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TITLE: Muscle Activity and Fatigue During Pushups Performed By Women: An Electromyographic and Videographic Analysis of 15 Muscles

Introduction:

The pushup is one of three activities performed by all persons in the Army during the Army Physical Fitness Test (APFT). While the exercise is used intuitively to improve, maintain and assess upper body strength, there is a paucity of information available establishing which muscles are utilized. There is also no information regarding the firing patterns of these muscles.

The use of dynamic electromyography in conjunction with video analysis has become a practical tool in the assessment of complex biomechanical activities. Studies have reported muscle firing patterns during athletic activities including swimming,¹⁻⁴ baseball pitching⁵⁻⁸ and batting,⁹ and shoulder rehabilitation programs.¹⁰⁻¹² Inferences to differences between healthy and injured athletes^{2,4} as well as between professional and amateur athletes⁷ have been made based on this information. To our knowledge, only a single study has attempted to delineate muscle activity during the pushup.¹³ Limited conclusions can be drawn from this earlier study due to the use of surface EMG to assess complex and layered muscle activity patterns.

Over 500,000 active army personnel perform the pushup as a routine training exercise.¹⁴ They are also required to perform pushups as a main event during the Army Physical Fitness Test (APFT) semi-annually.¹⁵ The military system provides a unique

situation in which to examine certain aspects of the pushup. A direct comparison can be made between individuals of different performance abilities. This is most evident among women, where a wide range between the standards for minimal and maximal accepted performance exists. Training for the pushup portion of the APFT has traditionally involved simply practicing the pushup itself. It has been suggested that the best training to achieve a quantitative difference for a specific task is to repetitively perform the task itself.¹⁶ It has been observed; however, that despite communal and therefore similar training, certain individuals continue to experience difficulty in performing pushups in comparison to others. An informal analysis of the Physical Medicine and Rehabilitation clinic data base at Walter Reed Army Medical Center also suggests a temporal relationship between the rate of rotator cuff injuries and preparation and completion of the APFT.

The purpose of this study was to determine firing patterns and level of EMG activity of 15 muscles during the pushup in an elite group of military women. Differences in activity levels and firing patterns between this elite group and those generated by a group of marginal performers will be made. Anthropometric and demographic data which may underscore differences between the groups will also be assessed. This information may impact on training regimens used to improve the caliber of performance of less than proficient individuals. It may also lay the groundwork for preventative programs that may limit the development of upper body musculoskeletal injuries related to pushup performance.

Body

Methods

Subject Selection

70 consecutive volunteers were recruited through advertisements in local military newspapers. Inclusion criteria were designed to generate groups which represented military women at both the upper and lower strata of the physical fitness spectrum. The observational subjects were women on active or reserve duty, aged 18 to 51 years. Thirty-one women comprised Group I (Marginal), which was identified as those subjects who scored below 70 points (on average below the 41st percentile) on the pushup portion of the Army Physical Fitness Test (APFT). Group II (Elite) included 39 women, and were those subjects who scored above 90 points (on average above the 80th percentile) on the pushup portion of the APFT. All subjects had passed height and weight standards for the Army.¹⁷ The most recent APFT scores, from performances within the past six months, were verified by written documentation from each subject's chain of command. Subjects with acute or unstable medical problems, current injuries, a history of bleeding disorders or current use of antiembolic agents were not considered for the study. None of the subjects were pregnant. Informed consent was obtained from all subjects. All procedures had been approved by the Walter Reed Army Medical Center, Department of Clinical Investigation Human Use Committee and the Army Medical Research and Materiel Command Institutional Review Board.

Procedure

Anthropometric measurements including height (cm), weight (kg), shoulder span,

measured across the back from acromion to acromion (cm), arm length, measured from acromion to dorsal wrist crease (cm) were recorded. Body-mass index (BMI) was calculated by dividing the subject's weight by the square of her height (kg/m^2).¹⁸

Dynamic electromyography with intramuscular electrodes was used to define the activity of 15 trunk and upper extremity muscles. Due to technical problems, data from seven subjects (six from the elite group and one from the marginal group) was not included in the study. Twelve muscles were tested in 59 subjects (31 elite, 28 marginal). An additional 3 muscles were tested in 22 of these subjects (14 elite, 8 marginal). In four additional subjects (2 elite, 2 marginal) only three muscles were tested. Muscles tested on the subjects' non-dominant side included the flexor carpi ulnaris, biceps brachii, triceps brachii (medial head)¹⁹, anterior deltoid, middle deltoid, posterior deltoid, pectoralis major, middle trapezius, rhomboid major, latissimus dorsi, rectus abdominis, and supraspinatus. The 3 additional muscles noted above included the infraspinatus, teres minor, and subscapularis.

Electrodes consisted of paired 44 gauge, 100 mm, nickel chromium alloy, Teflon coated hook wires with 2 mm bared tips. A 25 gauge, 30 mm needle served as the insertion cannula (Nicolet Biomedical, Madison, WI). Following aseptic skin preparation, the electrodes were inserted into each muscle following the technique outlined by Basmajian.²⁰ Muscle and motor point region localization followed that outlined by Perotto.²¹ Each muscle was passively moved through its full range of motion and the exposed portions of the electrodes were looped and secured with transparent tape to safeguard against movement and dislodgement. Accuracy of wire placement was confirmed by manual muscle testing and EMG signal display.

Prior to testing, 10 seconds of EMG data were recorded with the subject kneeling at rest, to establish background noise levels. This EMG noise was digitally subtracted from the baseline during data collection.

The subjects were allowed adequate time to stretch self-selected muscle groups prior to data collection. Each subject also practiced several pushups in the desired position and cadence so as to insure a standard performance technique. A metronome was used to regulate and monitor the speed at which the pushups were performed.

An attempted 15 second maximal isometric contraction (MIMMT) was then performed for each tested muscle, following the manual muscle testing techniques described by Kendall for the activation of individual muscles.²² Standardized methods established for performance of the pushup as outlined in the Army Physical Fitness Training field manual were employed.²³ Following a 10 minute rest period, the subject performed 5 consecutive pushups at a rate of one per second. The five pushups were repeated, following 10 minute rest periods, in each of three different hand positions. Spacing between the hands was calculated based on a measurement of the subject's interacromial distance (shoulder span), a neutral position being 1.5 x the interacromial distance. Narrow and wide positions were calculated respectively at 1.2 and 1.8 times the interacromial distance. This calculation was established from pilot data confirming subjects' comfort and perception of hand placement during pushups. The order of pushup sets performed in each of the hand positions was randomly assigned based on a computer generated randomization program. Next, one set of pushups was performed to fatigue. Lastly, a second set of 15 second isometric contractions was performed.

Data Processing

A Noraxon Myosystem 2000 EMG machine (Noraxon, Phoenix, AZ) linked to an Intel 486DX based personal computer was used for digital signal processing. The EMG signal was sampled at a rate of 2000 cycles per second (cps) to prevent aliasing.²⁴ Analog signals were digitally filtered with a bandpass set between 16 and 500 cps.

Each subject's pushups were recorded with a VHS video camera (Panasonic, Japan) operating at 33 cps. Real time synchronization of video and EMG data was achieved with a videographic genlock system.

Data Analysis

Two intervals per pushup were discerned during slow motion video analysis at 3.3 cps, named accordingly descent and ascent. The descent commenced with the first downward motion of the shoulders from the starting position and ended at the beginning of the ascent. The ascent began with the first upward motion of the shoulder from the bottom position and ended with the cessation of upward motion of the shoulders. Subtle differences in the speed at which pushups were performed between subjects and also between the descent and ascent intervals performed by individuals were normalized, to allow for comparisons of equivalent positions during the pushup. Each interval was divided into 9 phases. The raw EMG signals were rectified and smoothed utilizing a 7.5 ms moving average window. The area under the fully integrated EMG signal curves for each of the 18 phases per pushup were calculated. A similar process was undertaken for EMG signals recorded initially, during the MIMMT testing for each muscle. A normalization value (100%), based on the peak one second MIMMT for each muscle, was calculated for the equivalent time frame of each phase of each

pushup per subject. The phase values were reported as a percentage of the normalization value (% MIMMT). Data from the second and fourth pushups were analyzed separately. Consecutive phases were averaged, collapsing the data into 9 phases per pushup. Data from the second and fourth pushups were then averaged.

Statistical Analysis

Descriptive analyses including means and standard deviations for each of the 9 phases per pushup, were generated for each group (SPSS for Windows, 6.1.2a, Chicago, IL).

To correct for unequal variances between groups, a logarithmic transformation was performed prior to comparison between groups. An unbalanced repeated measures analysis of variance (ANOVA) was performed to assess differences in EMG activity (%MIMMT) for individual muscles between groups (BMDP, Berkeley, CA). Differences in EMG activity from phase to phase (individual muscle firing pattern) between groups were also determined. When significant differences in firing patterns for individual muscles were discerned between groups, decomposition of the ANOVA by phase was reported to further delineate which aspect of the firing patterns were different. To control for type I error in the face of multiple testing, the α level was set at $\alpha=.01$.

Demographic and anthropometric data were compared between marginal and elite groups using independent samples t-test for each variable. The α level for type I error was set at $\alpha=.05$. When significant differences were observed between groups for individual variables, they were added as covariates in the ANOVA. This was done to assess their effect on group differences in EMG activity.

Missing Data

Occasionally during this study, hardware malfunction (e.g., movement or dislodgement of electrodes) precluded collection of every data point. In 2 subjects, more than 25% of data points for an individual muscle were lost. In these cases, as the data generated was of dubious value, the data for the entire muscle was not included in the analysis. Aside from these cases, out of a total of 7,074 data points, only 24 points were missing (.3%). These missing points were assigned the value of the previously occurring data points.

Synchronized electromyographic and video information was collected during the isometric contractions and during the 3 sets of pushups.

Results

Demographic and Anthropometric Data

A summary of demographic and anthropometric data per group may be found in Table 1. The age of all subjects in the study ranged from 21 to 50 years, with a mean age of 32.8 years (SD 7.5). Ages between groups were not significantly different.

Both the raw score (i.e., number of pushups performed) and points awarded (i.e., scaled value based on soldiers age bracket) for the pushup portion of the APFT were significantly different between groups ($p < .001$). This suggested an accurate discrimination between groups based on the selection criteria.

Mean arm lengths were longer among subjects in the marginal group, in comparison to those in the elite group ($p = .025$). Mean heights were similar between groups ($p = .084$) as were shoulder span ($p = .061$). The latter two measurements, while not statistically

significant, were trending toward significance. Ratios of arm length to height and shoulder span to arm length were not significantly different between groups ($p=.843$). These findings suggest that subjects in the marginal group tended to be minimally larger than those in the elite group, but proportionally the same. Given the weakness of these correlations, their clinical significance remains unclear.

A significant difference between groups was noted; however, for mean weight ($p<.001$). The marginal group mean weight was nearly 9 kg greater than that of the elite group. Body-mass indices were also calculated. The body-mass index limits the influence of height on overall weight.²⁵ Mean body-mass index was 25.24 kg/m² for the marginal group and 22.99 kg/m² for the elite group ($p=.003$). These indices may also be expressed as falling within ranges of percentage of desirable weight according to the 1983 Metropolitan Life Insurance Company Tables. The mean for the marginal group fell in the 115-119% of desirable weight while the elite group mean was within the 100-114% range.²⁵

Muscle Activity

EMG activity for individual muscles, for each of the 9 phases of the pushup can be found in Tables 2 to 4. EMG activity is represented as the percent of the maximal isometric manual muscle test normalization value for each muscle. Data from the ANOVA can be found in Table 5. The p values for group interactions and group by phase interaction are reported. Muscles which consistently generated EMG activity less than 15% MIMMT are included in the table. Because these muscles generated little activity and were unlikely to significantly fatigue at this level of firing,¹⁶ they were not included in the results or discussion.

Flexor Carpi Ulnaris

A significant difference in EMG activity ($p < .001$) was noted in the flexor carpi ulnaris (Figure 1). The marginal group demonstrated 75 % more EMG activity at the beginning of the descent than the elite group. This difference narrowed to 37% at the bottom of the pushup cycle and increased again during the ascent, culminating with the marginal group exhibiting 47% more EMG activity than the elite group at the end of the ascent. The firing patterns between groups were also significantly different ($p = .009$). Decomposition of the ANOVA by pushup phase revealed that the difference in firing pattern reflected the more rapid decrement in EMG activity in the marginal group during the middle portion of the descent.

In terms of % MIMMT, the flexor carpi ulnaris activity steadily decreased in both groups from the beginning of the descent to the end of the ascent. Muscle activity for the marginal group decreased from its peak of 56% MIMMT at the onset of descent to 28% MIMMT at the end of the ascent. The elite group maintained fairly constant flexor carpi ulnaris muscle activity of around 32% MIMMT during the first half of the descent, reaching its nadir of 19% MIMMT at the end of the ascent.

Biceps Brachii

EMG activity of the biceps brachii muscle in the marginal group was found to be significantly greater than that in the elite group ($p = .01$) (Figure 2). At the onset of the descent, EMG activity was 50% greater in the marginal group compared to the elite group. This difference narrowed during the descent. An increasing difference in EMG activity was noted during the ascent. The marginal group EMG activity was 66% greater than that for

the elite group at the beginning of the ascent, increasing to 155% greater by the end of the ascent. Unlike the EMG activity, the firing patterns were similar between groups ($p=.243$).

Peak biceps brachii muscle activity began with the initial portion of the descent. The marginal group started the descent with its peak activity of 24% MIMMT while the elite group sustained a more even peak activity of about 16% MIMMT during the first half of the descent. Both marginal and elite groups reached their nadirs of 15% and 9% MIMMT respectively at the onset of the ascent. The marginal group then produced a burst of muscle activity during the middle portion of the ascent, ranging from 15 to 27% MIMMT. The elite group; however, held a fairly constant muscle activity with only a 2% variability in MIMMT during the middle of the ascent.

Triceps brachii (medial head)

The medial head of the triceps generated similar levels of EMG activity throughout the phases of the pushup in the elite and marginal groups ($p=.098$)(Figure 3). Firing patterns were also essentially the same ($p=.036$).

During the first half of the descent, stable peak triceps muscle activity was demonstrated in both groups, 108% MIMMT in the marginal group and 83% MIMMT in the elite group. Thereafter triceps use precipitously diminished throughout the descent. Its use continued to diminish, but to a lesser extent, during the first portion of the ascent, falling to a nadir of 23% and 26% MIMMT for the marginal and elite groups, respectively. Triceps muscle activity then steadily increased during the ascent, returning at the end to 36% MIMMT for the marginal group and 30% MIMMT for the elite group.

Anterior Deltoid

The anterior deltoid showed similar EMG activity between the elite and marginal groups ($p=.025$)(Figure 4). Muscle firing patterns for the anterior deltoid were also similar between groups across the phases of the pushup ($p=.656$).

The anterior deltoid displayed its peak activity of 131% MIMMT for the marginal group and 118% MIMMT for the elite group at the beginning of the descent. The marginal group reached its nadir of approximately 51% MIMMT one phase interval sooner than the elite group. The elite group's lowest muscle activity of 41% MIMMT was at the onset of the ascent. Both groups gradually increased anterior deltoid muscle activity throughout the ascent to 78% MIMMT for the marginal group and 63% MIMMT for the elite group.

Middle Deltoid

Similar EMG activity between the marginal and elite groups was noted in the middle deltoid throughout the pushup phases ($p=.08$)(Figure 5). The firing patterns; however, were significantly different between groups ($p<.001$). This difference was seen primarily in the greater slope of the curve for the marginal group at the end of the descent, as determined by decomposition of the ANOVA by pushup phase.

Peak activity of the middle deltoid, 71% MIMMT, sequentially followed that of the anterior deltoid, particularly in the marginal group. This peak activity was demonstrated toward the end of the descent for the marginal group. For the elite group, peak muscle activity of 55% MIMMT was shown at the beginning of the descent, decreasing initially, then rising to 53% MIMMT at the same phase as the marginal group's peak activity. Both groups then decreased muscle activity at the end of the descent. The nadir of both groups

was reached at the beginning of the ascent, 24% MIMMT for the marginal group and 22% MIMMT for the elite group. A gradual increase in muscle activity was seen during the remainder of the ascent, both groups reaching 33% MIMMT by the end of the ascent.

Posterior Deltoid

EMG activity in the posterior deltoid was significantly different between marginal and elite groups ($p=.008$)(Figure 6). Throughout the phases of the pushup, the elite group produced greater percent MIMMT than the marginal group. At the onset of the descent, the marginal group had only 35% of the EMG activity found in the elite group. The marginal group approached the EMG activity of the elite group, with 85% of the elite group activity at the end of the descent. Halfway through the ascent, the marginal group EMG activity had decreased to about half the EMG activity of the elite group before increasing again at the end of the ascent, peaking at 18% MIMMT and 26% MIMMT respectively. The firing patterns of the posterior deltoid also produced significant differences between groups ($p<.001$). Differences between firing patterns was most notable at the end of the descent where the marginal group was increasing its muscle activity while the elite group was in the midst of a decline in muscle activity.

The posterior deltoid showed peak muscle activity at different phases between the marginal and elite groups. Peak activity for the marginal group, 25% MIMMT, was demonstrated toward the end of the descent. The elite group's peak activity was present at the onset of the descent. Both groups produced nadirs at the onset of the ascent, 10% MIMMT for the marginal group and 17% MIMMT for the elite group, with gradual increase in muscle activity during the ascent.

Pectoralis Major

The marginal and elite groups showed similar EMG activity in the pectoralis major throughout the phases of the pushup ($p=.125$) (Figure 7). The firing patterns, however, were significantly different between the groups ($p<.001$). Analysis of the individual phases revealed that the difference in firing pattern represented the more rapid decrement in EMG activity in the marginal group at the end of the descent.

The peak muscle activity in the pectoralis major was at the onset of the descent for both marginal and elite groups, 167% and 133% MIMMT respectively. Use of the pectoralis major in the marginal group rapidly waned, reaching its nadir of 45% MIMMT at the end of the descent. The elite group showed a more gradual decline in muscle activity during the descent. The elite group's nadir of 53% MIMMT was demonstrated in the early portion of the ascent. During the last half of the descent and first phase of the ascent, the marginal group produced less pectoralis major muscle activity than the elite group. At all other phases of the pushup, the marginal group's muscle activity exceeded that for the elite group by 14 to 41% MIMMT.

Rectus Abdominis

The EMG activity of the rectus abdominis muscle was similar between the two groups ($p=.725$) (Figure 8). No significant difference between groups was additionally found for the firing patterns of the rectus abdominis ($p=.973$).

Peak rectus abdominis muscle activity was shown at the beginning of the descent for the marginal and elite groups, 88% and 81% MIMMT respectively. Muscle activity declined gradually until the end of the descent when there was a steeper drop for both groups. The

nadir for both groups was reached at the onset of the ascent: 46% MIMMT for the marginal group and 43% MIMMT for the elite group. As the top of the pushup cycle was approached, a gradual increase in marginal and elite group muscle activity was noted. Throughout the pushup phases, the marginal group maintained 7 to 12 percent greater muscle activity than the elite group.

Supraspinatus

Both elite and marginal groups demonstrated similar EMG activity in the supraspinatus muscle ($p=.350$) (Figure 9). No significant difference was determined in the firing pattern between groups ($p=.269$).

Peak supraspinatus activity occurred at the onset of the descent, with 108% MIMMT for the marginal group and 94% MIMMT for the elite group. Muscle activity of the marginal group was greater than that for the elite group by 15% at its peak activity and increased to 30% greater muscle activity in the marginal group by the end of the descent. Percent MIMMT decreased during the descent before finding its nadir for both groups at the end of the descent and the beginning of the ascent. During the ascent the marginal group's muscle activity initially exceeded that for the elite group by 21% then dramatically dropped to 3% less than the elite group in the second phase of the ascent. Both groups increased their muscle activity during the last half of the ascent, with the marginal group producing 11 to 14 percent more activity than the elite group.

Infraspinatus

The overall EMG activity in the infraspinatus muscle was similar between groups ($p=.449$) (Figure 10). The firing pattern of the infraspinatus was also found to be similar

throughout the phases of the pushup between elite and marginal groups ($p=.259$).

Peak muscle activity for the infraspinatus was 65% MIMMT for both groups at the onset of the descent. Its nadir, 34% MIMMT in the marginal group and 27% MIMMT in the elite group, was demonstrated at the end of the descent. By the end of the descent the marginal group was producing over 25% more muscle activity than the elite group. This difference in muscle activity between groups diminished during the ascent where both groups showed a steady increase in muscle activity.

Teres Minor

EMG activity in the teres minor was similar between elite and marginal groups ($p=.073$) (Figure 11). The firing patterns were found to have significant differences between the groups ($p=.009$). However, decomposition of the ANOVA by pushup phase failed to show a statistically significant difference in firing pattern between groups. The values approached significance ($p=.017$) during the middle of the descent where there was a sharper decline in the elite group's muscle activity compared to the marginal group.

A wide range of peak activity was found in the teres minor at the onset of the descent, 110% MIMMT for the elite and 72% MIMMT for the marginal groups. By the end of the descent, this difference between groups diminished to only 6%, before reaching the nadir of 39% and 38% MIMMT for the elite and marginal groups respectively. Teres minor activity during the first quarter of the ascent was held at a constant level before its gradual increase in activity during the remainder of the ascent. Throughout the pushup phases in the teres minor, the elite group demonstrated more EMG activity than the marginal group.

Subscapularis

A significant difference in EMG activity between groups was noted throughout the pushup phases in the subscapularis muscle ($p=.001$) (Figure 12). The firing patterns between elite and marginal groups were found to be similar ($p=.999$).

Peak activity of 147% MIMMT for the marginal group and 111% MIMMT for the elite group occurred early in the descent. A sharper decline in activity was seen in the marginal group during the last phase of the descent. The nadir for both groups was reached during the first phase of the ascent, with 71% MIMMT for the marginal group and 50% MIMMT for the elite group. Muscle activity gradually increased for both groups through the rest of the ascent. The marginal group produced muscle activity that was 32 to 46 percent MIMMT greater than that of the elite group throughout the phases of the pushup.

Effect of weight on pushup performance

To account for the possible influence of weight differences between groups on EMG activity, weight was added as a covariate in the ANOVA performed for each muscle in which significant differences in EMG activity had been observed. The ANOVAs remained significant solely for the group effect after the weight differences between the groups were considered.

Comparison of Muscle Activity Based on Hand Placement

Statistical analysis of this portion of the data has not been completed at this time, but should be available presently.

Discussion

The pushup is a complex activity which requires precise activation of upper body muscles. During performance of the pushup, the upper extremity is maintained in contact with the ground. Thus, in distinction to activities such as swimming or pitching, it is a closed kinetic chain exercise. Muscles commonly understood to accelerate the arm or to be prime movers of certain motions are utilized in different patterns than in open kinetic chain activities.

Muscle activity demonstrated by women performing the pushup were divided arbitrarily into three categories to aid in the description of the results. Marked activity represented % MIMMT greater than 100. Moderate activity connoted % MIMMT between 50 and 100. Less than 50% MIMMT signified the Minimal category of muscle activity. EMG activity for all muscles during each phase can be found in Figures 13 to 21.

Each of the fifteen tested muscles exerted peak activity during the first two phases of the descent. During the descent, while the arm is extending, horizontally abducting, and internally rotating, the anterior deltoid and pectoralis major muscles are lengthening as they contract. The triceps is firing in the moderate range during the initial descent, as the elbow is flexing. It is clear that the lengthening, eccentric contraction of these muscles produces the force needed for a controlled descent.

The subscapularis contracted in the marked range during the early descent. Moderate activity at the beginning of the descent was noted in the rest of the rotator cuff muscles, including the supraspinatus, teres minor, and infraspinatus. As a group, the rotator cuff activity was relatively more constant throughout the entire pushup than other muscles,

reflecting its function as the dynamic stabilizer of the glenohumeral joint. Greater activity in the subscapularis was predicted, given its relatively anterior position at the beginning of the descent. It undoubtedly provides dynamic stability and protection against anterior dislocation during the generation of substantial forces across the glenohumeral joint.

Moderate activity was also observed in the rectus abdominis during the initial phases of the descent. The abdominal muscles are integral to trunk control ^{26,27} and are utilized during the pushup to stabilize the torso.

Minimal activity during the early portion of the pushup was shown in the middle and posterior deltoids, biceps brachii and flexor carpi ulnaris. As noted, the anterior deltoid produced its greatest muscle activity during the beginning of the descent. As the muscle activity of the anterior deltoid decreased, that of the middle deltoid increased. As the arm internally rotates during the descent, the more lateral fibers of the deltoid gain mechanical advantage as they come into the plane of motion. Interestingly, the elite group predominated in EMG activity for the posterior deltoid over the marginal group during the descent. This may represent greater inherent strength in the elite group's posterior deltoid and their ability to generate the activity needed in a muscle of relative importance in the pushup.

The biceps brachii is commonly regarded an elbow flexor. Biceps muscle activity in the elite group was negligible throughout the phases of the pushup. The marginal group, however, demonstrated several bursts of biceps activity during the pushup, the first being at the onset of the descent. Similar to hamstring muscle firing at heel strike²⁸ of the gait cycle, the marginal group appeared to use the biceps muscle to stabilize the elbow while flexing the shoulder during this closed kinetic chain exercise. As a decelerator to the apparent free-fall

technique employed by marginal group subjects, the biceps was again active just before the bottom of the descent. The third increase in biceps activity was noted at the end of the ascent when the marginal group produced an eccentric contraction. Based on the percent MIMMT, the biceps and triceps muscles appear to be co-contracting in the marginal groups during the ascent, producing an overall stabilizing force about the elbow and between the superior and inferior glenoid in the shoulder.

Activity of the flexor carpi ulnaris predominated in both groups during the descent. Video analysis suggested a radial deviation and small wrist extension moment during this time frame. The flexor carpi ulnaris activity aided in stabilizing wrist motion during this period.

Muscle activity of all the tested muscles fell below the fiftieth percentile MIMMT by the onset of the ascent. None of these muscles produced marked activity during any phase of the ascent. By the end of the ascent, after a gradual increase in muscle activity, only the anterior deltoid, pectoralis major, and subscapularis showed moderate activity. As the elbow extended and the shoulders flexed, adducted and minimally externally rotated, most of the tested muscles were shortening as they contracted (i.e., concentric contraction) during the ascent. These findings are consistent with those of Knuttgen suggesting that more force is generated by a muscle during eccentric contraction than during concentric contraction.¹⁶ Although it has been anecdotally suggested that the triceps muscle is the primary muscle which needs to be strengthened in order to do more pushups, our findings suggest that while it is an important muscle during the activity, the anterior deltoid and pectoralis muscle are more important. The triceps only showed moderate activity during the descent and minimal

activity during the ascent while the two muscles spanning the shoulder generated marked activity during the descent and moderate activity during the ascent. Because the hands are fixed on the ground, the forces generated by the anterior deltoid and pectoralis muscle pull the proximal portion of the humerus into flexion, causing an extension moment at the elbow. While the triceps may aid in stabilizing the elbow during the ascent, the primary extensors of the elbow in this closed kinetic chain are the anterior deltoid and the pectoralis major.

The marginal group demonstrated greater EMG activity than the elite group in all tested muscles with the exception of the posterior deltoid and teres minor throughout all phases of the pushup. In order for the marginal group to generate the same force as the elite group, a greater number of muscle fibers were necessarily recruited, thereby producing greater overall EMG muscle activity in the marginal group. This increased muscle activity may also predispose these muscles to fatigue earlier than those in their elite group counterparts. This may be particularly important in consideration of the extremely high level of EMG activity generated by the rotator cuff muscles.

The elite group appeared to have a more controlled descent with a smoother decrease in muscle activity compared to the marginal group. The marginal group also showed a more rapid decrease in muscles activity during the descent, which was borne out during decomposition of the ANOVA by phase. Observational analysis of the video was consistent with this finding. Subjects in the elite group efficiently used certain muscles to achieve a controlled rhythm, without wide vacillations. The marginal group alternatively, generated greater activity to stabilize themselves at the top of the descent and proceeded into a virtual free fall, with EMG activity returning to levels more similar to that of the elite group at the

bottom of the descent. The marginal group's large difference between peak and nadir muscle activity implies a greater force applied to the shoulder, particularly during the descent of the pushup. The eccentric nature of the muscle contractions, such as those observed during descent, have been reported to generate a higher incidence of muscle injury that either isometric or concentric contractions,²⁹⁻³¹ thus creating a greater susceptibility to soft tissue injuries, and particularly to injuries of the rotator cuff.

The anthropometric analyses revealed some interesting results. A shorter average arm length was confirmed in the women who performed well on the APFT pushup.

This difference, however, was only approximately one centimeter. Thus, the clinical significance of this subtle difference in arm lengths between groups remains unclear. Future studies assessing differences in torque generation across the joints of the upper extremity between subjects with differing arm lengths may determine if in fact this difference is clinically relevant. Neither the subject's height nor the ratio of arm length to height proved to be significantly different between the groups. Subjects in the marginal group were on average heavier than elite subjects. Yet when weight was added as a covariate to the ANOVA, weight was found to have no significant effect on the subject's ability to do pushups. Broader shoulders, possibly creating a more stable fulcrum between upper extremities and trunk, produced no advantage in pushup performance.

This study suggests that an ability to efficiently generate force in specific muscles and to effectively control their firing sequences underlies the ability of elite performers to score higher on the pushup portion of the APFT than their marginal counterparts.

Conclusion

The pushup has been utilized by the Army since the 1950's as an exercise to improve upper body strength. Advancement in the military is predicated on performance in a variety of tests, one of which is the APFT. Thus the ability to perform well on the APFT may have implications in terms of promotion and procurement of specific jobs which require adequate upper body strength.²³ Over the last 25 years, a significant demographic shift has occurred in the U.S. armed forces. Women comprised only 1% of active duty soldiers in 1971.³² Currently, 13.5% of the Army is female.¹⁴ Jones demonstrated that during basic training, women sustained nearly twice the number of musculoskeletal injuries experienced by their male counterparts.³³ As women continue to make ever increasingly important contributions to all aspects of military preparedness, measures which may enhance their performance and limit the development of injuries need to be strongly considered.

Knapik's review of the literature on the APFT show the pushup to have merit as a test of absolute muscle endurance and muscle strength.³⁴ However, employing the pushup as the sole method for training has dubious benefits. Pilot data for this study showed that a subject is lifting (i.e., pushing up) the equivalent of more than half of her body weight during the pushup. If a subject has difficulty performing even a small number of pushups, a reasonable training program may begin with isotonic exercises starting with less than half her body weight, with emphasis on strengthening the muscle groups known to require the most marked activity, namely the pectoralis major, anterior deltoid, and subscapularis. It would appear that the bench press exercise would provide an excellent cross-training effect to improve the pushup. Further studies should be performed to identify the best exercise to achieve

increased strength of the specific muscles most active in the pushup without causing concomitant shoulder injury.

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Table 1. Anthropometric & Demographic Data
($p=0.05$ significant)

Variable	Minimum Group	Maximum Group	Significance
N	29	34	
APFT Raw Score	18.20 (4.51)	54.94 (11.59)	$p < .001^*$
APFT Percentile	65.38 (4.49)	97.56 (3.49)	$p < .001^*$
Age	32.76 (7.67)	33.00 (7.54)	$p = .900$
Height (cm)	165.75 (8.67)	162.25 (7.16)	$p = .084$
Weight (kg)	69.32 (9.32)	60.46 (7.56)	$p < .001^*$
Body Mass Index	25.24 (2.96)	23.00 (2.82)	$p = .003^*$
Arm Length	54.81 (3.23)	53.09 (2.72)	$p = .025^*$
Shoulder Span	44.49 (2.81)	43.26 (2.33)	$p = .061$
Arm-Height Ratio	0.3308 (0.013)	0.3273 (0.014)	$p = .310$
Shoulder Span- Arm Length Ratio	0.8134 (0.056)	0.8159 (0.045)	$p = .843$

(Standard Deviation)

Table 2. EMG activity of individual muscles for each group, during each pushup phase (% MIMMT)

[illegible]

Table 3. EMG activity of individual muscles for each group, during each pushup phase (% MIMMT)

Phase Interval	Posterior Deltoid		Pectoralis Major		Middle Trapezius		Rhomboid Major		Latissimus Dorsi	
Descent	Minimum (n=28)	Maximum (n=31)	Minimum (n=28)	Maximum (n=31)	Minimum (n=28)	Maximum (n=31)	Minimum (n=28)	Maximum (n=31)	Minimum (n=28)	Maximum (n=31)
Top	17 (15)	48 (45)	167 (50)	133 (54)	9 (6)	9 (6)	10 (5)	10 (6)	8 (5)	12 (9)
2	15 (13)	41 (41)	151 (64)	132 (62)	8 (6)	8 (5)	8 (4)	9 (5)	8 (4)	13 (12)
3	16 (13)	41 (39)	105 (53)	100 (52)	7 (4)	8 (6)	8 (4)	9 (5)	7 (4)	13 (11)
4	25 (25)	36 (45)	76 (46)	88 (64)	7 (4)	7 (4)	9 (8)	7 (5)	7 (4)	11 (9)
Bottom Ascent	17 (13)	20 (22)	45 (21)	62 (56)	5 (2)	5 (3)	6 (4)	6 (5)	5 (3)	8 (7)
6	10 (8)	17 (20)	51 (22)	53 (32)	6 (4)	6 (3)	6 (3)	7 (6)	6 (6)	7 (4)
7	11 (13)	24 (31)	73 (33)	59 (35)	7 (4)	7 (4)	9 (6)	7 (5)	6 (4)	8 (7)
8	13 (21)	26 (31)	76 (30)	58 (26)	7 (4)	8 (4)	10 (6)	8 (5)	6 (5)	8 (8)
Top (Standard Deviation)	18 (26)	26 (25)	89 (33)	63 (25)	7 (3)	7 (3)	9 (7)	7 (6)	6 (4)	7 (6)

Table 4. EMG activity of individual muscles for each group, during each pushup phase (% MIMMT)

Phase Interval	Rectus Abdominus		Supraspinatus		Infraspinatus		Teres Minor		Subscapularis	
Descent	Minimum (n=28)	Maximum (n=31)	Minimum (n=28)	Maximum (n=31)	Minimum (n=10)	Maximum (n=16)	Minimum (n=10)	Maximum (n=16)	Minimum (n=9)	Maximum (n=15)
Top 1	88 (50)	81 (38)	108 (62)	94 (48)	65 (24)	65 (20)	72 (31)	110 (57)	146 (28)	111 (39)
2	82 (48)	75 (33)	92 (54)	75 (38)	59 (29)	61 (20)	68 (43)	101 (38)	147 (35)	109 (41)
3	75 (44)	70 (37)	74 (41)	61 (38)	60 (22)	53 (23)	59 (42)	85 (34)	135 (29)	98 (40)
4	65 (37)	61 (30)	65 (38)	51 (32)	54 (24)	42 (19)	53 (31)	65 (27)	122 (32)	86 (44)
Bottom 5	48 (27)	44 (19)	48 (25)	37 (20)	34 (12)	27 (10)	39 (24)	45 (23)	83 (35)	60 (41)
Ascent										
6	46 (32)	43 (18)	47 (23)	39 (21)	35 (12)	32 (14)	38 (13)	39 (16)	71 (37)	50 (20)
7	51 (34)	47 (24)	57 (31)	59 (22)	37 (11)	36 (21)	47 (16)	47 (19)	76 (39)	54 (24)
8	54 (31)	48 (28)	60 (33)	54 (27)	39 (11)	37 (25)	47 (21)	51 (24)	82 (37)	60 (28)
Top 9	55 (38)	52 (30)	65 (39)	57 (34)	39 (13)	40 (24)	50 (24)	58 (23)	99 (40)	68 (29)

(Standard Deviation)

Table 5. p values for Repeated Measure Analysis of Variance for Logarithmically Transformed Data
(p=0.01 significant)

Muscle	Group	Phase	Group by Phase
Flexor Carpi Ulnaris	<.001*	.002*	.009*
Biceps Brachii	.01*	<.001*	.243
Triceps Brachii	.098	<.001*	.036
Anterior Deltoid	.025	<.001*	.656
Middle Deltoid	.08	<.001*	<.001*
Posterior Deltoid	.008*	<.001*	<.001*
Pectoralis Major	.125	<.001*	<.001*
Middle Trapezius	.441	<.001*	.572
Rhomboid Major	.432	<.001*	.162
Latissimus Dorsi	.023	<.001*	.469
Rectus Abdominus	.725	<.001*	.973
Supraspinatus	.350	<.001*	.269
Infraspinatus	.449	<.001*	.259
Teres Minor	.073	<.001*	.009*
Subscapularis	.001*	<.001*	.999

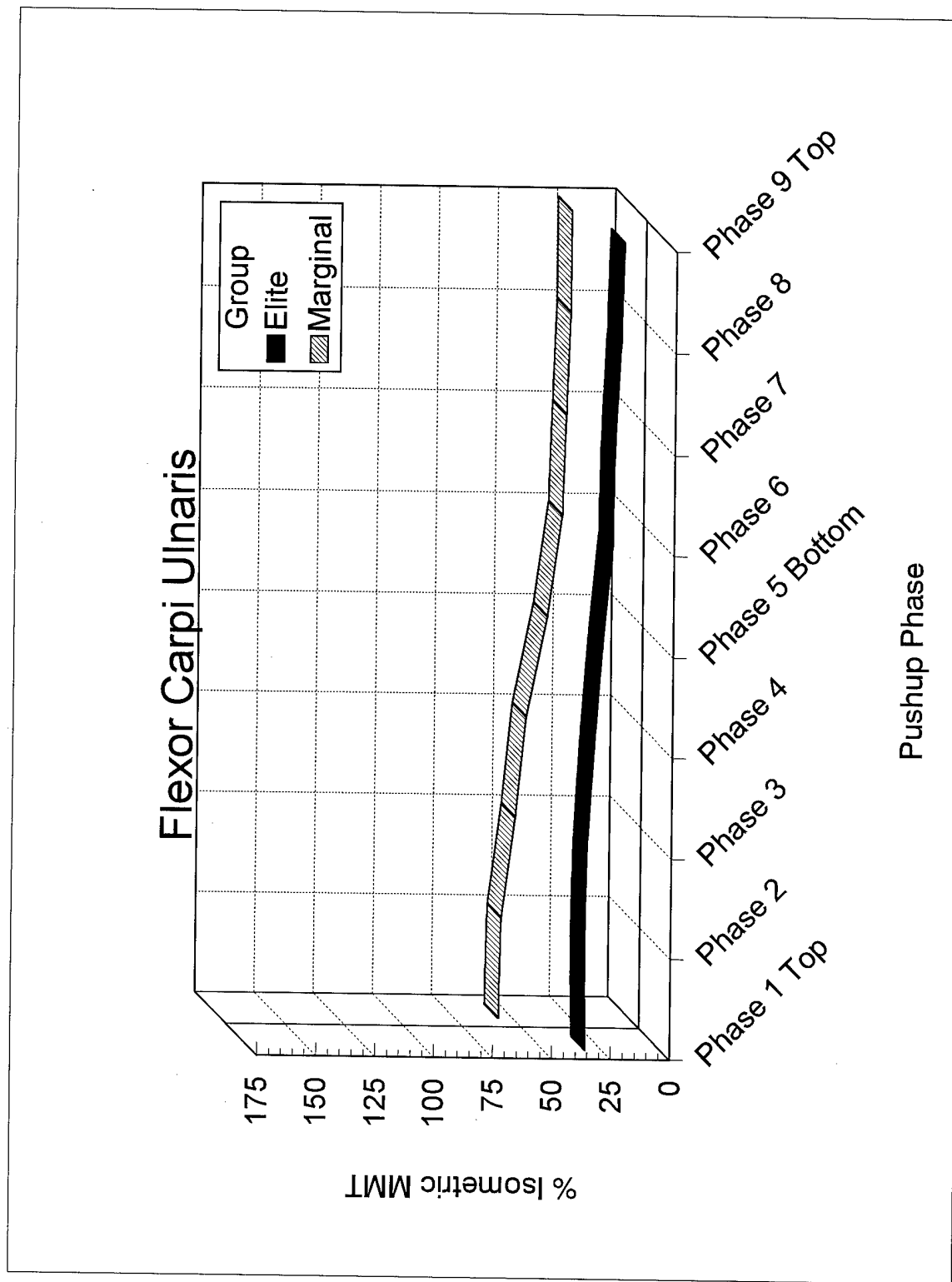
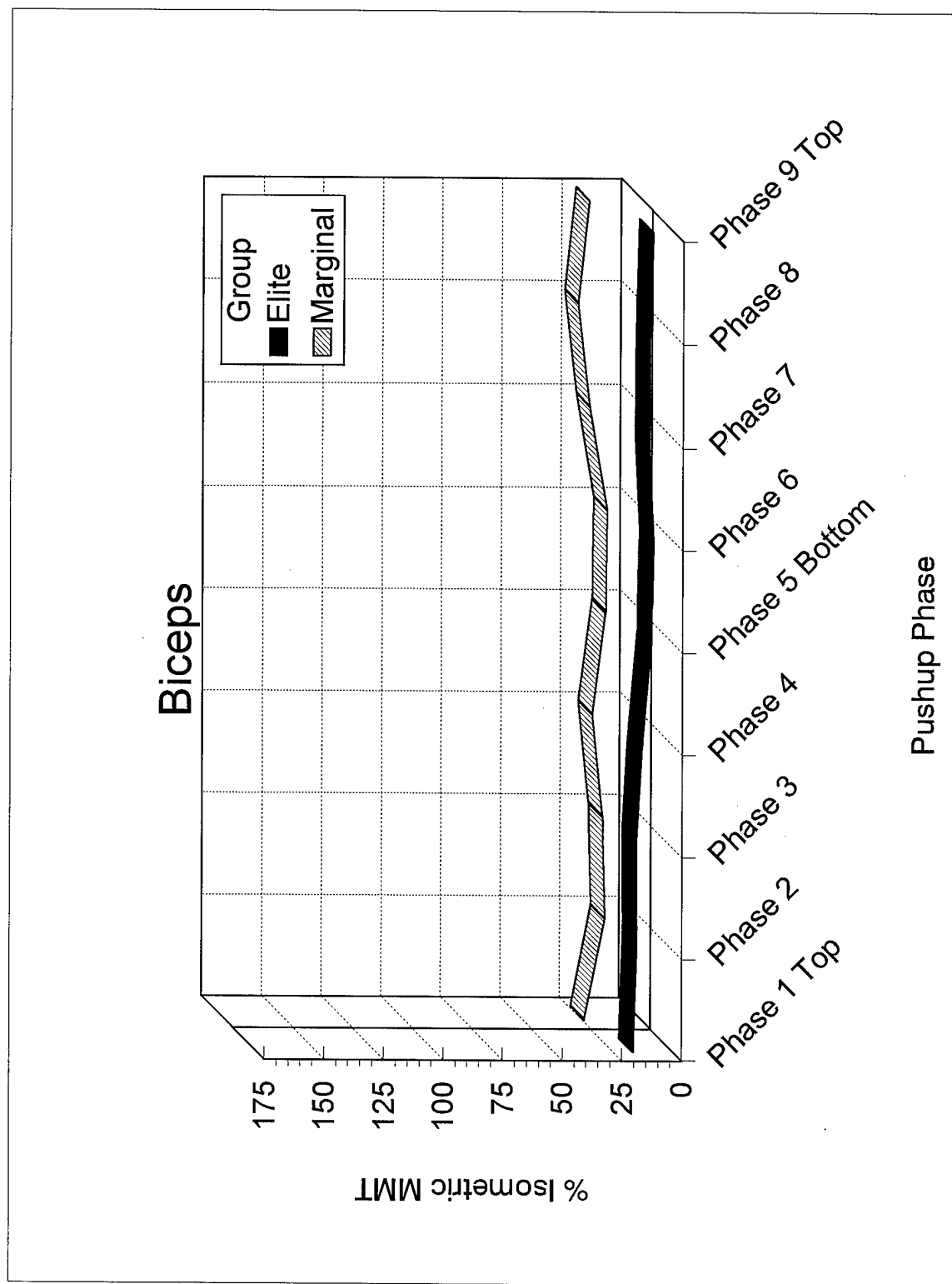


Figure 2



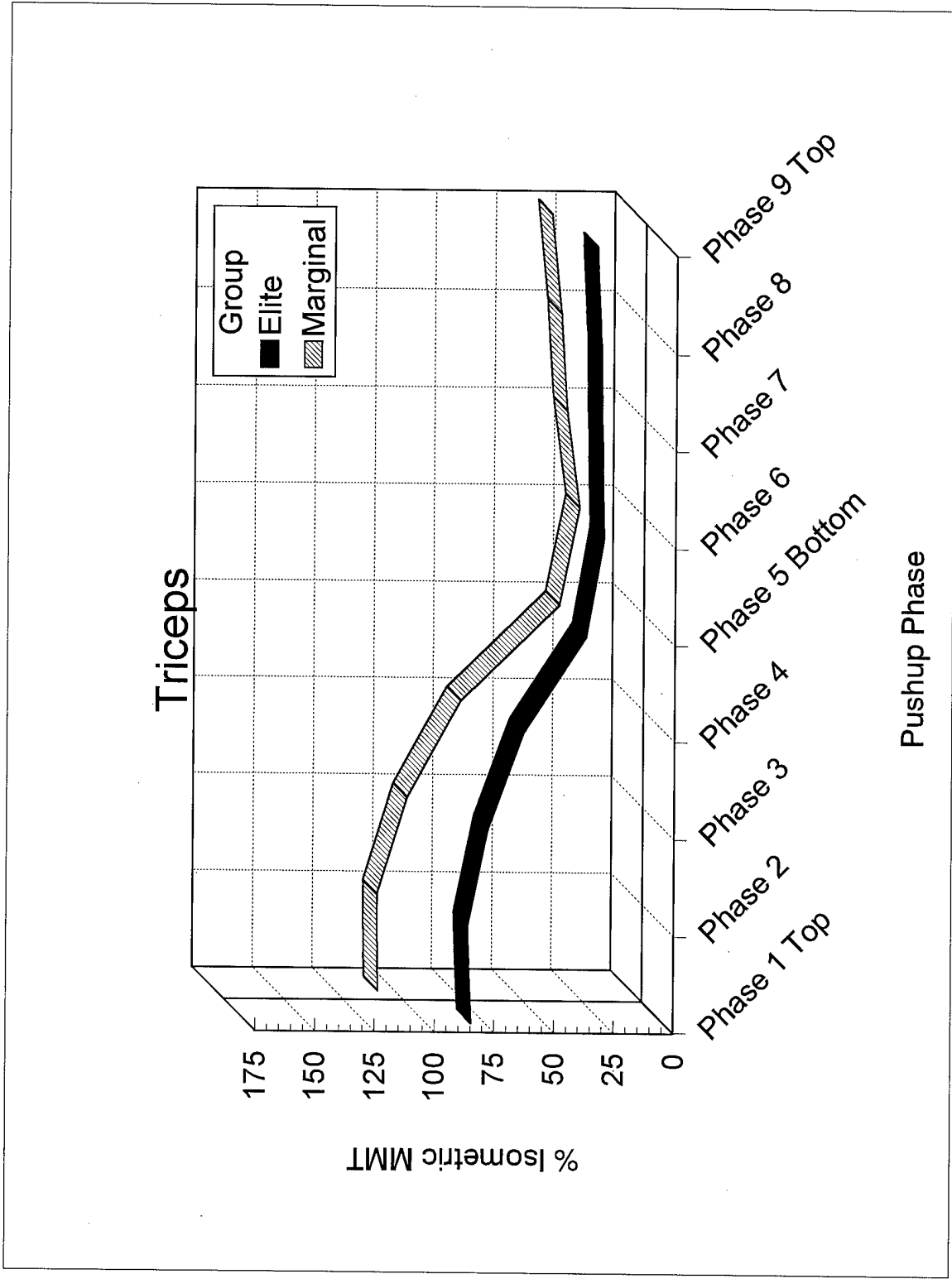
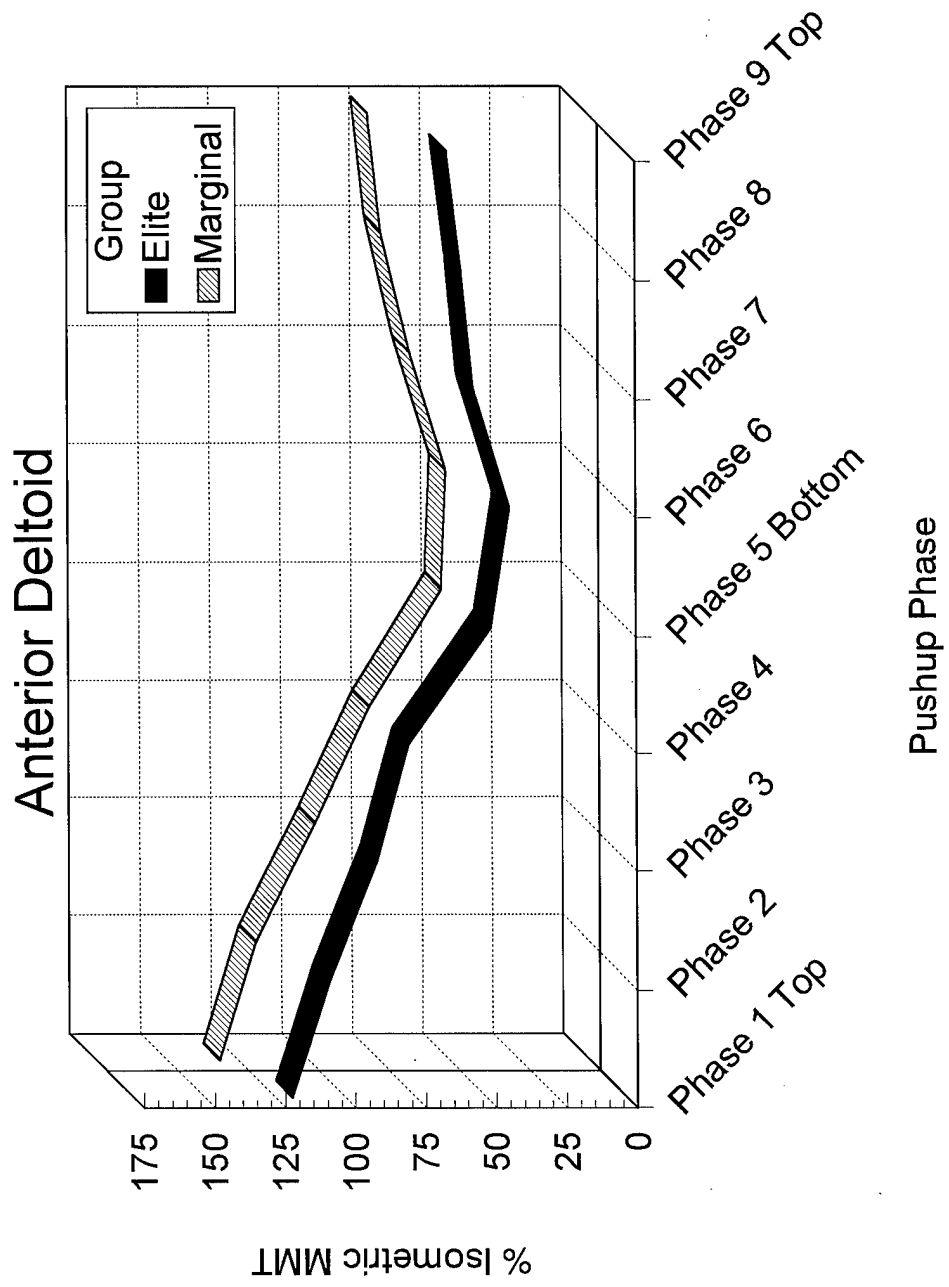


Figure 4



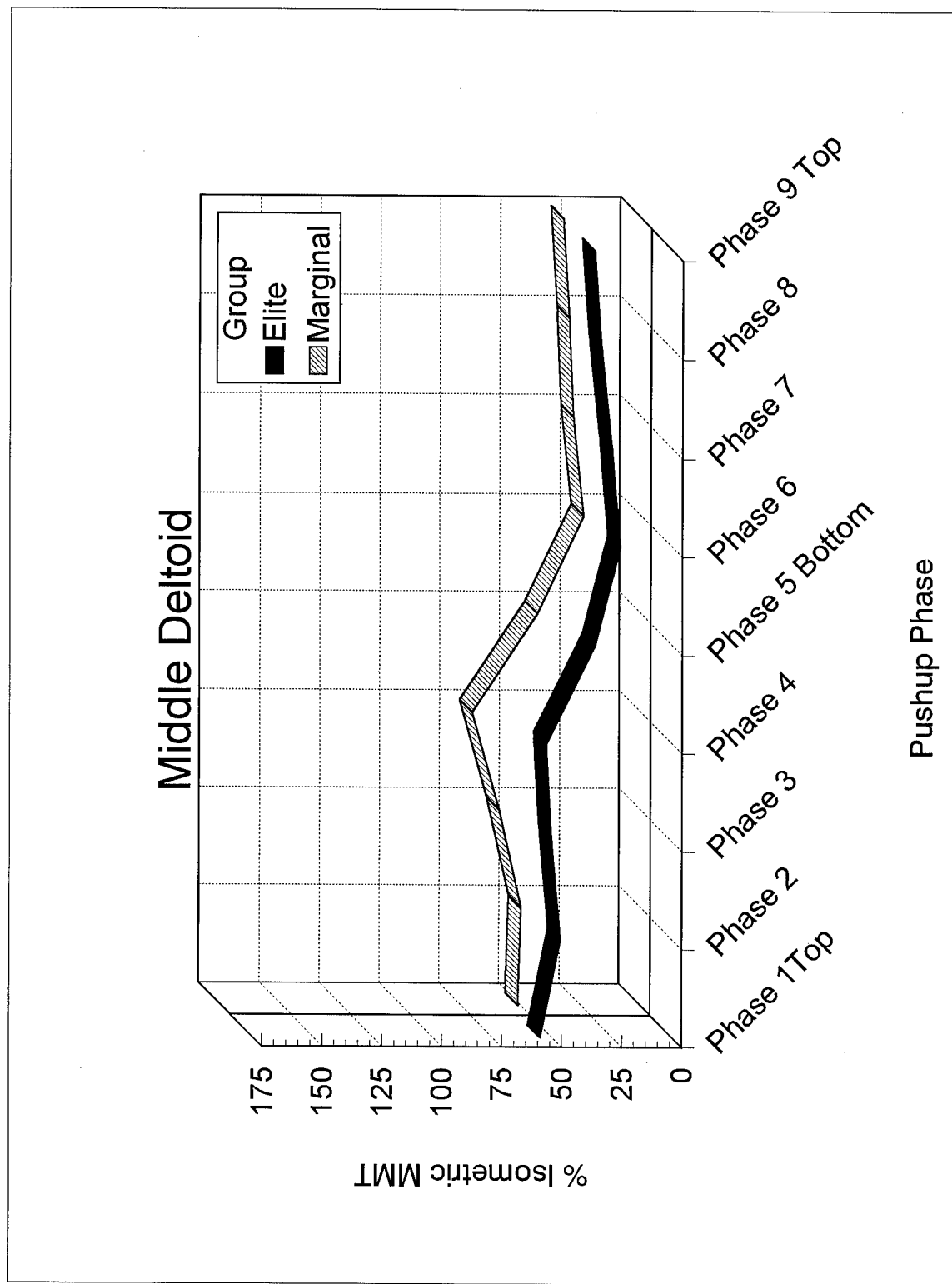


Figure 6

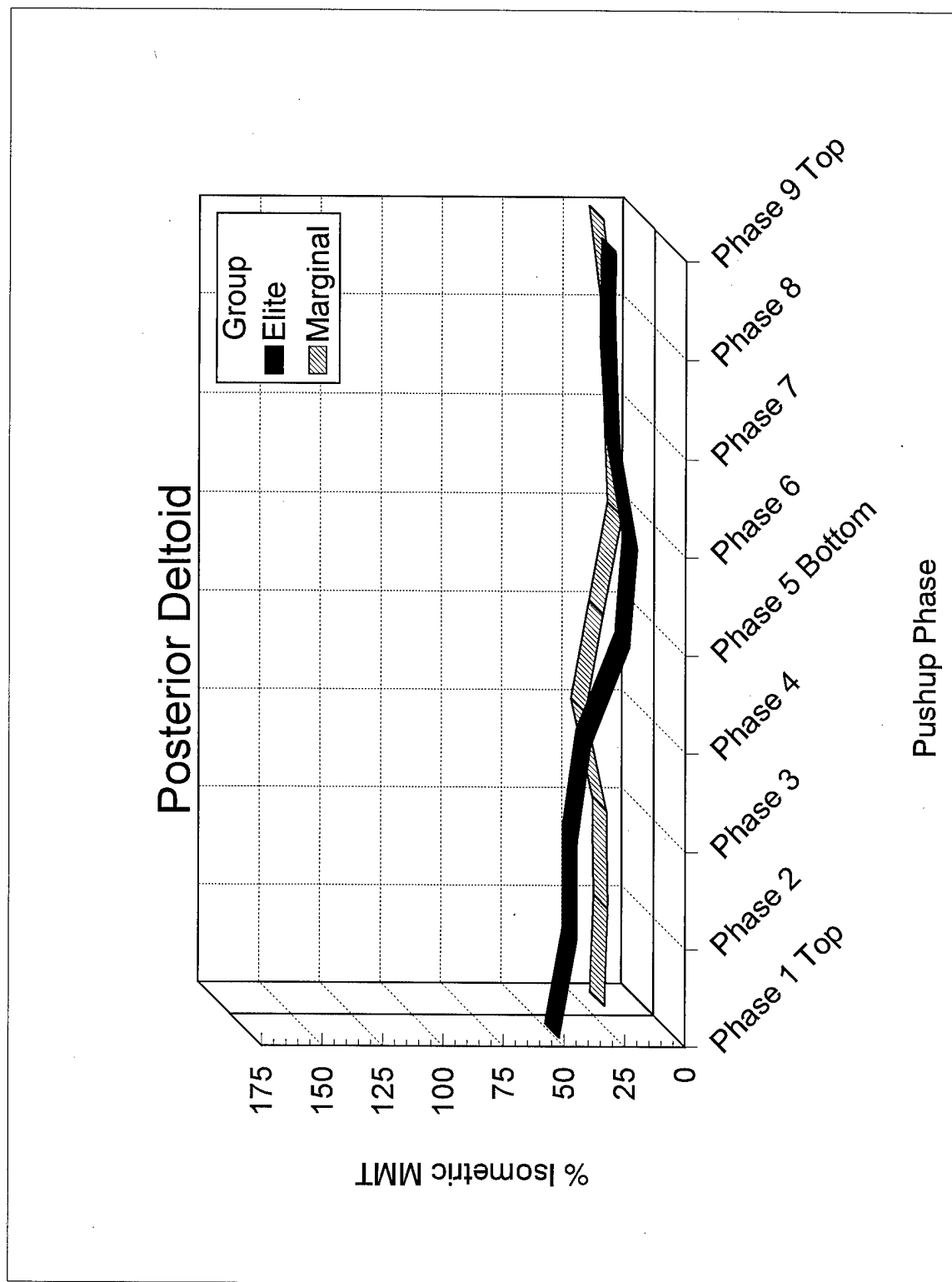


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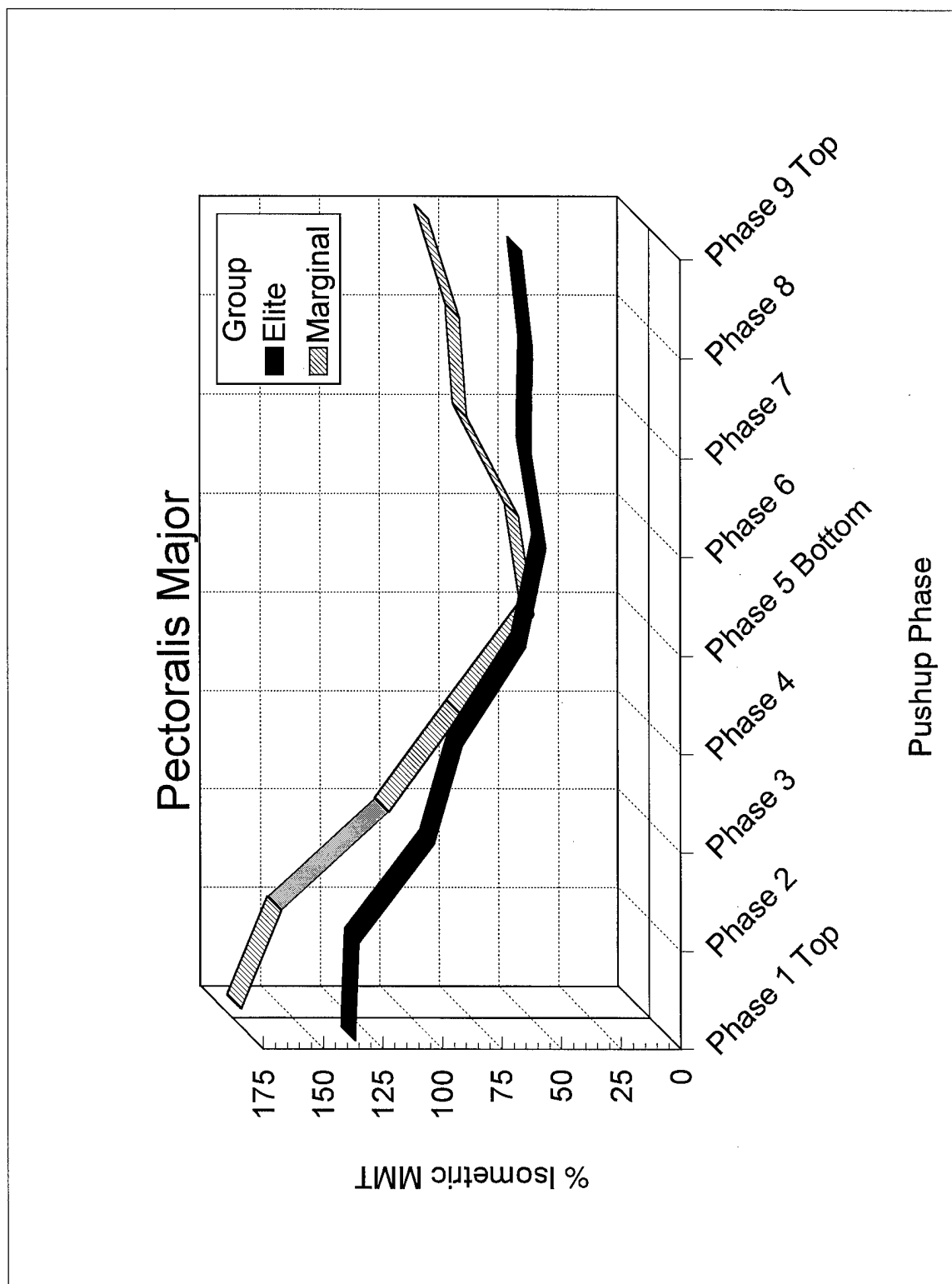


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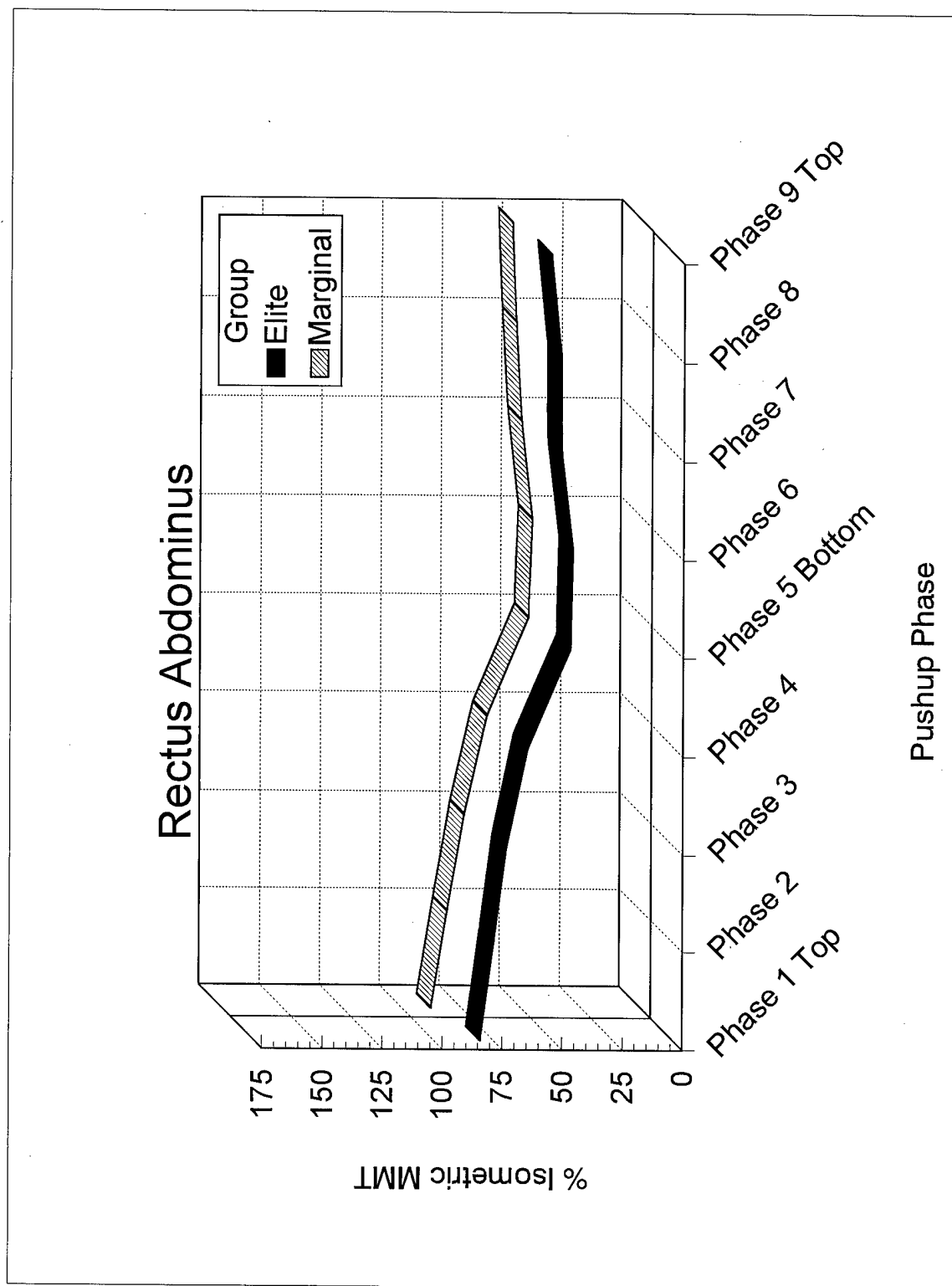


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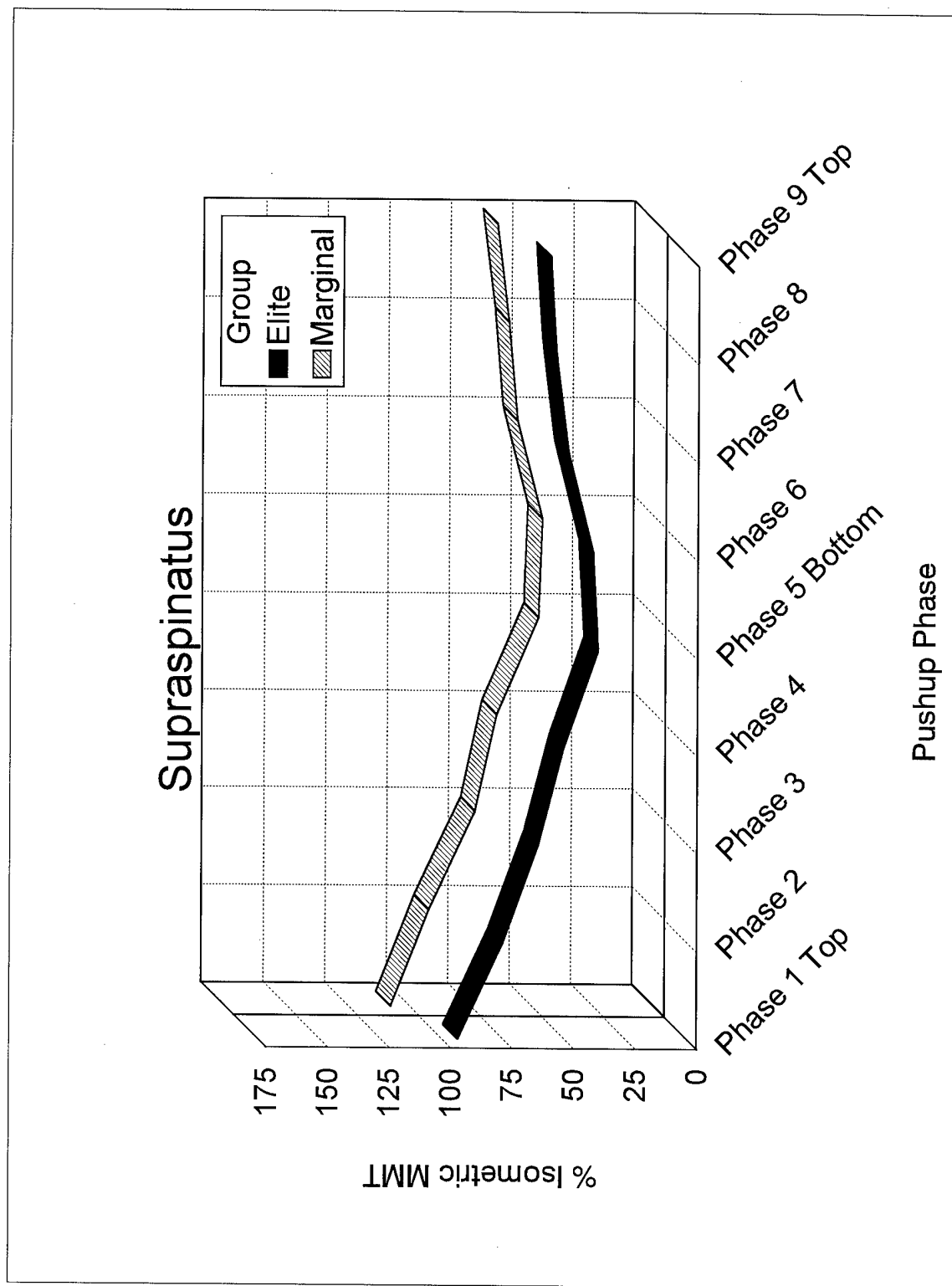


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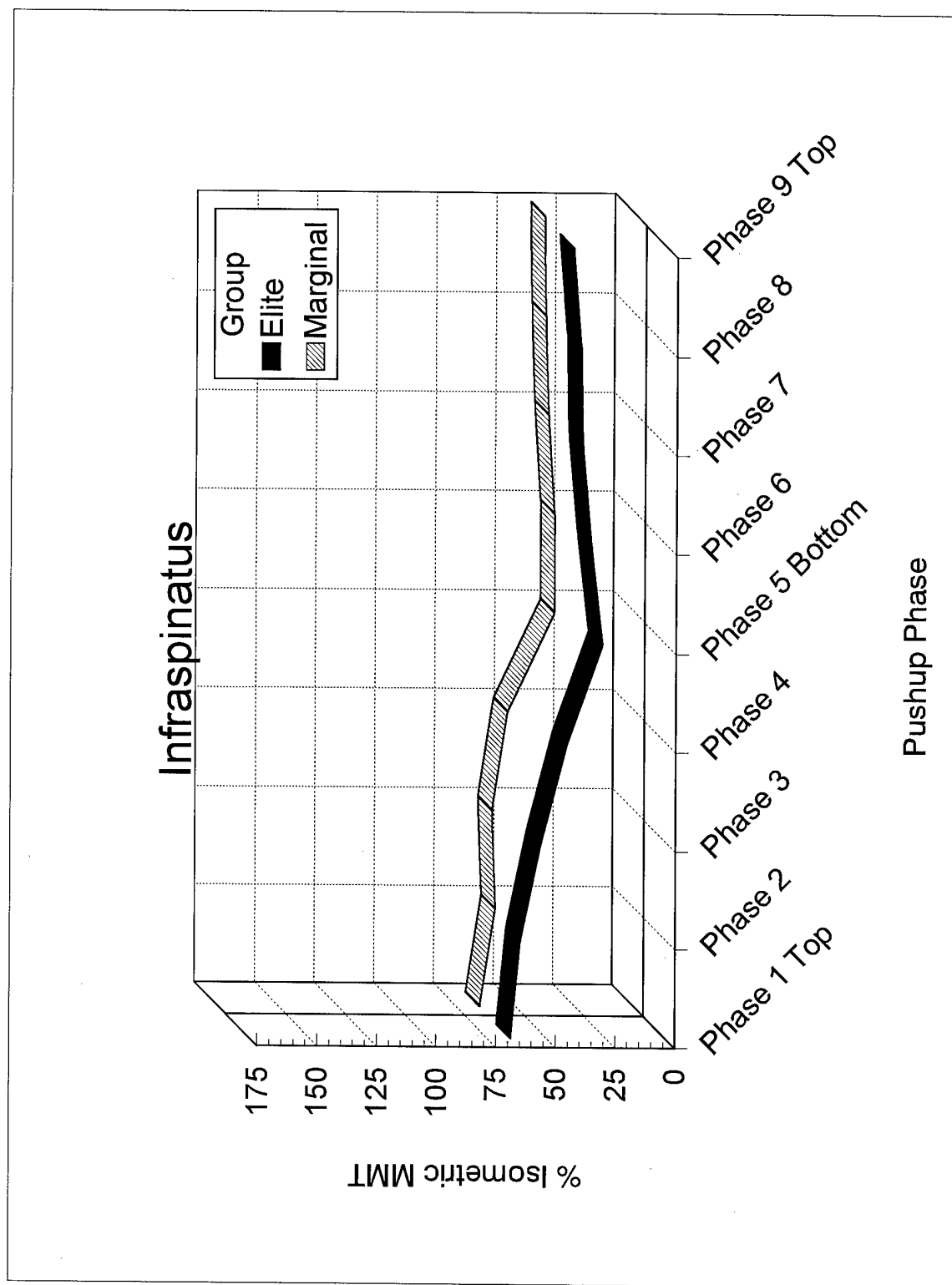


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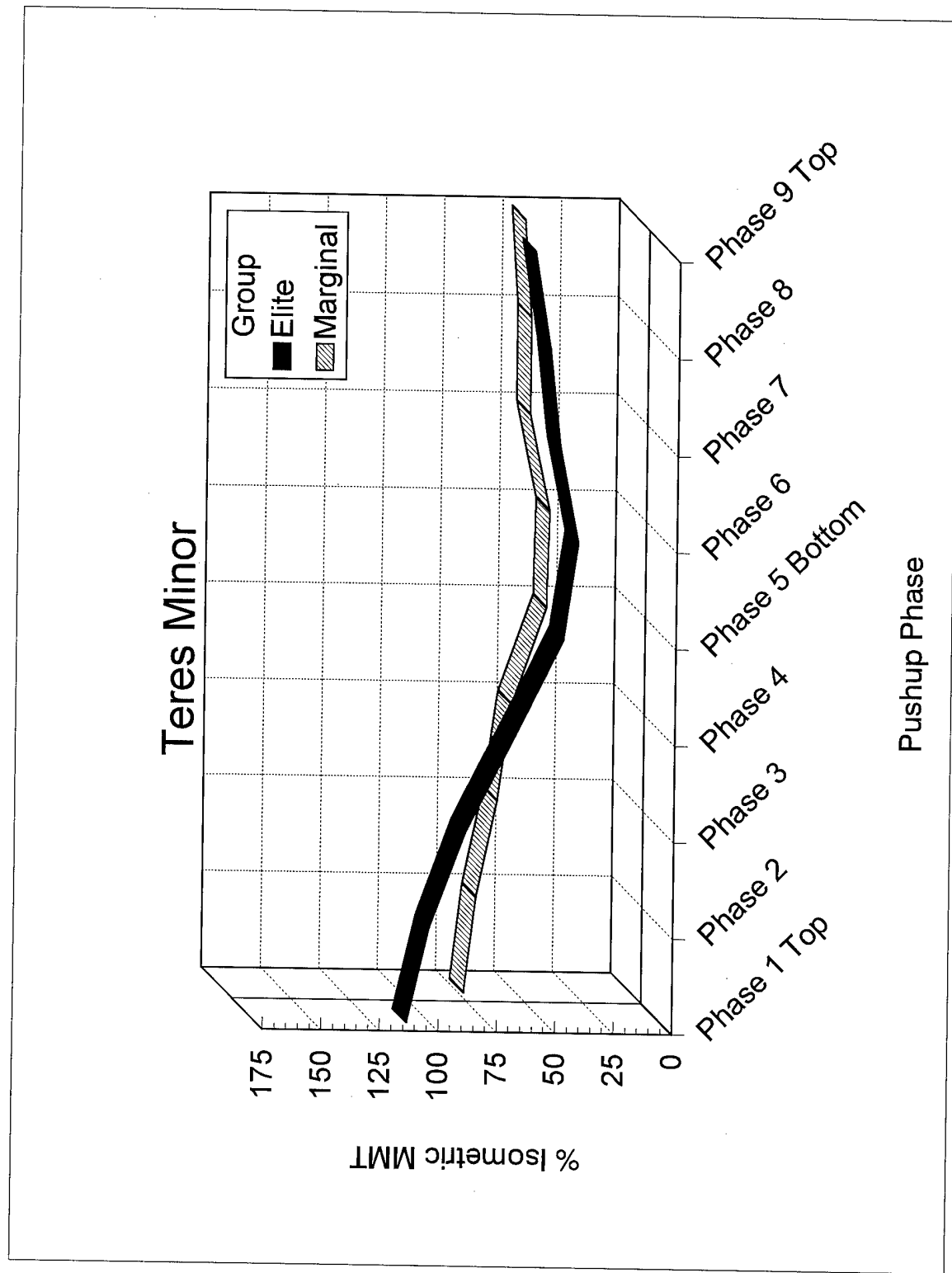
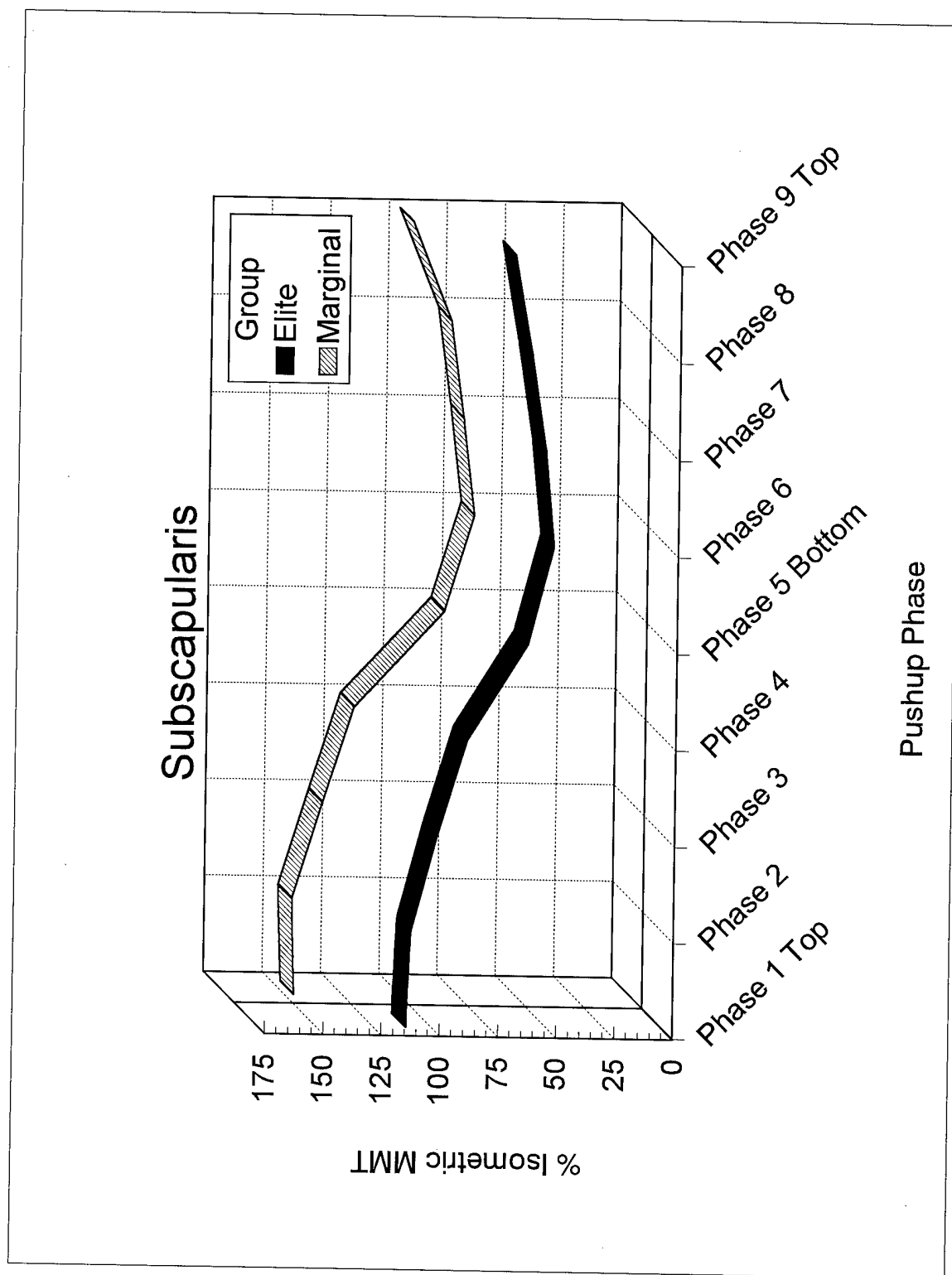
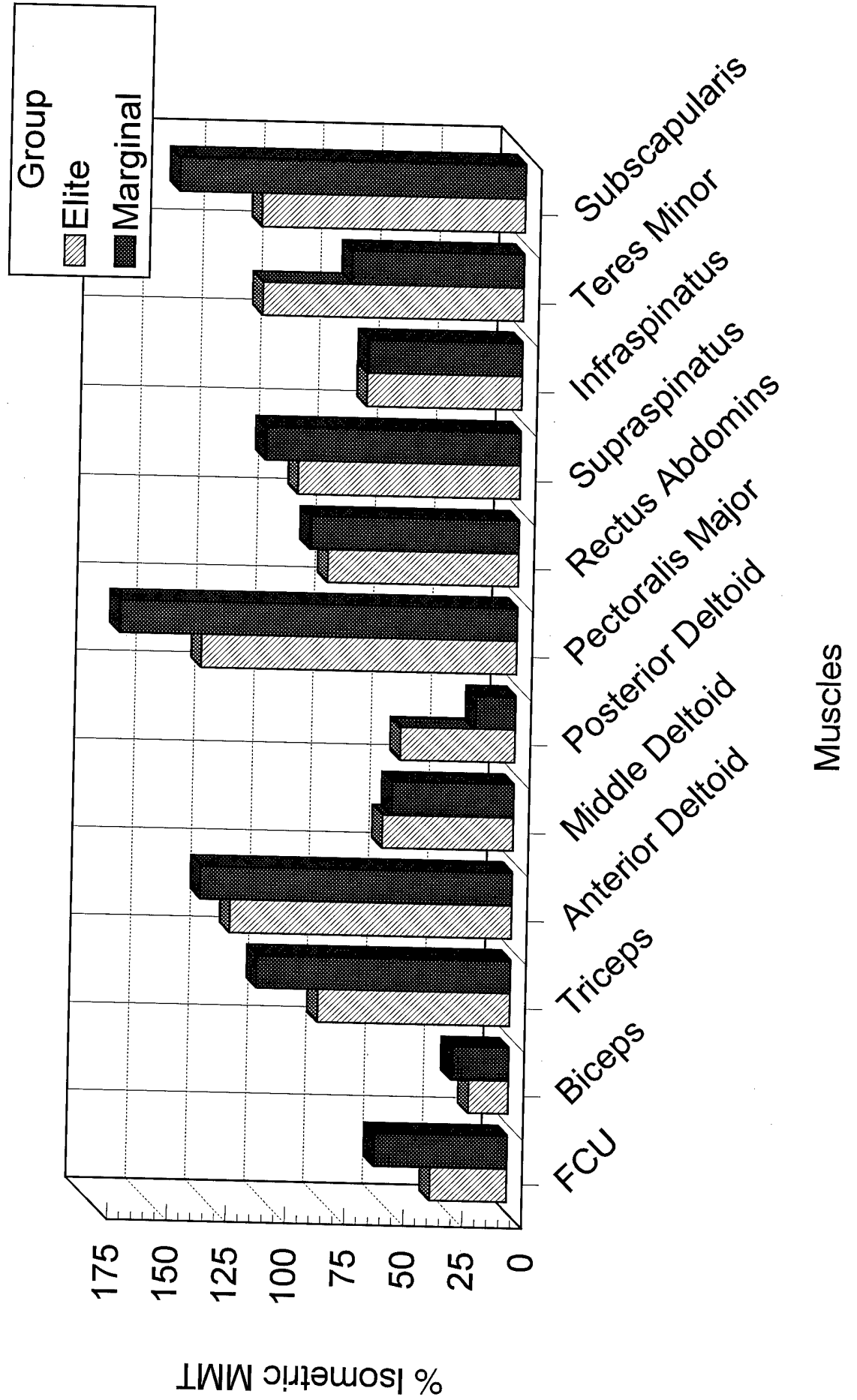


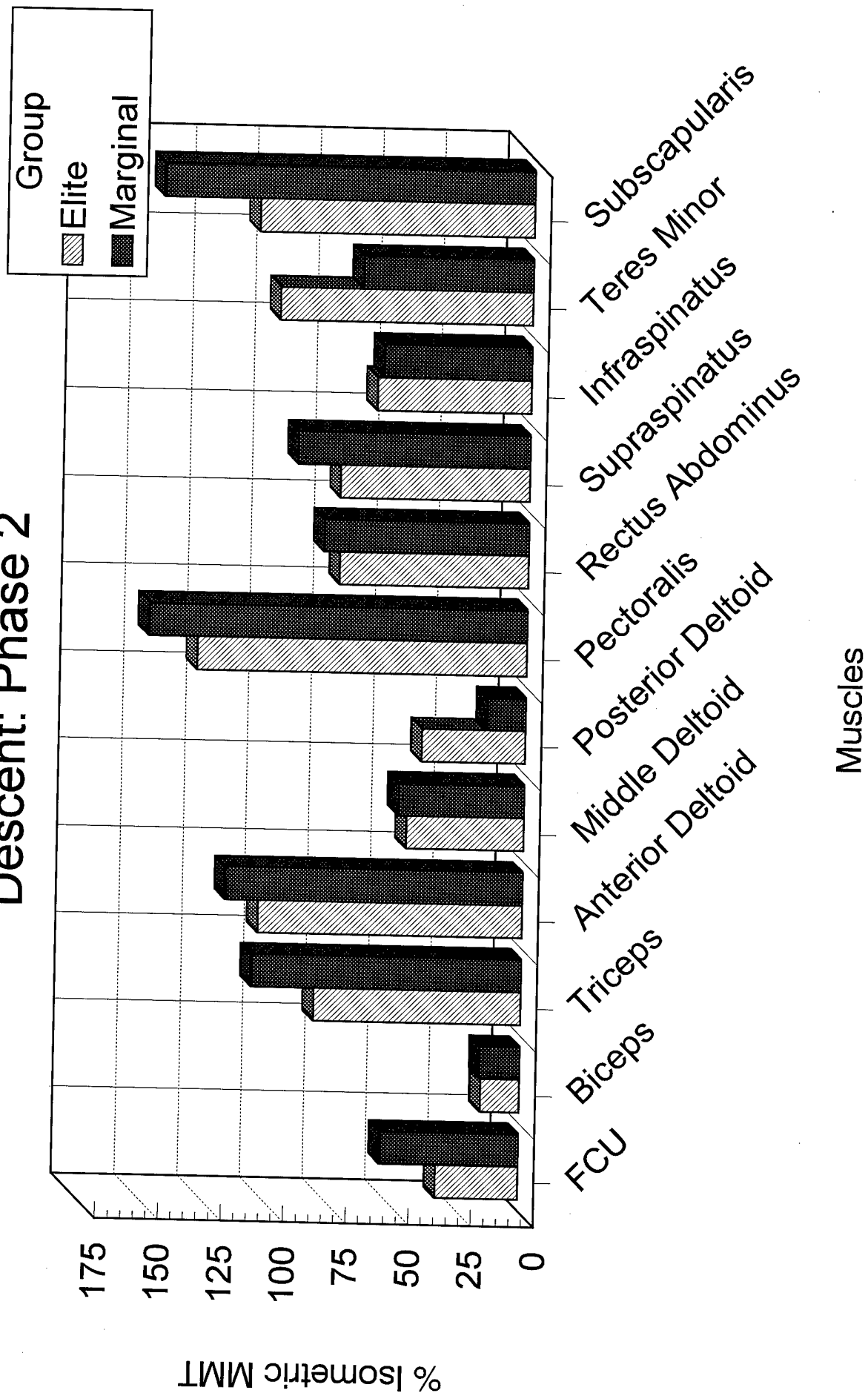
Figure 12

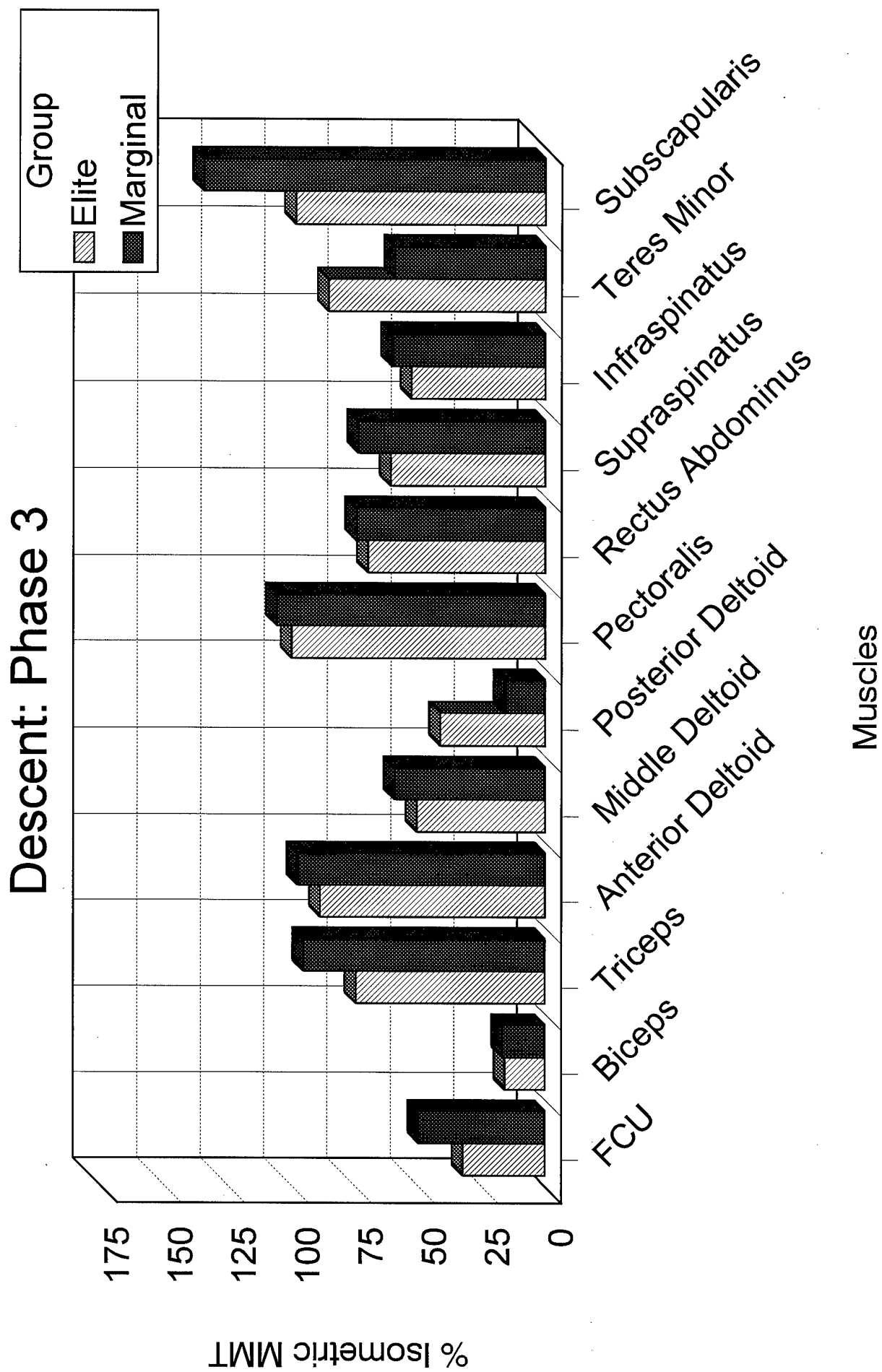


Top: Phase 1

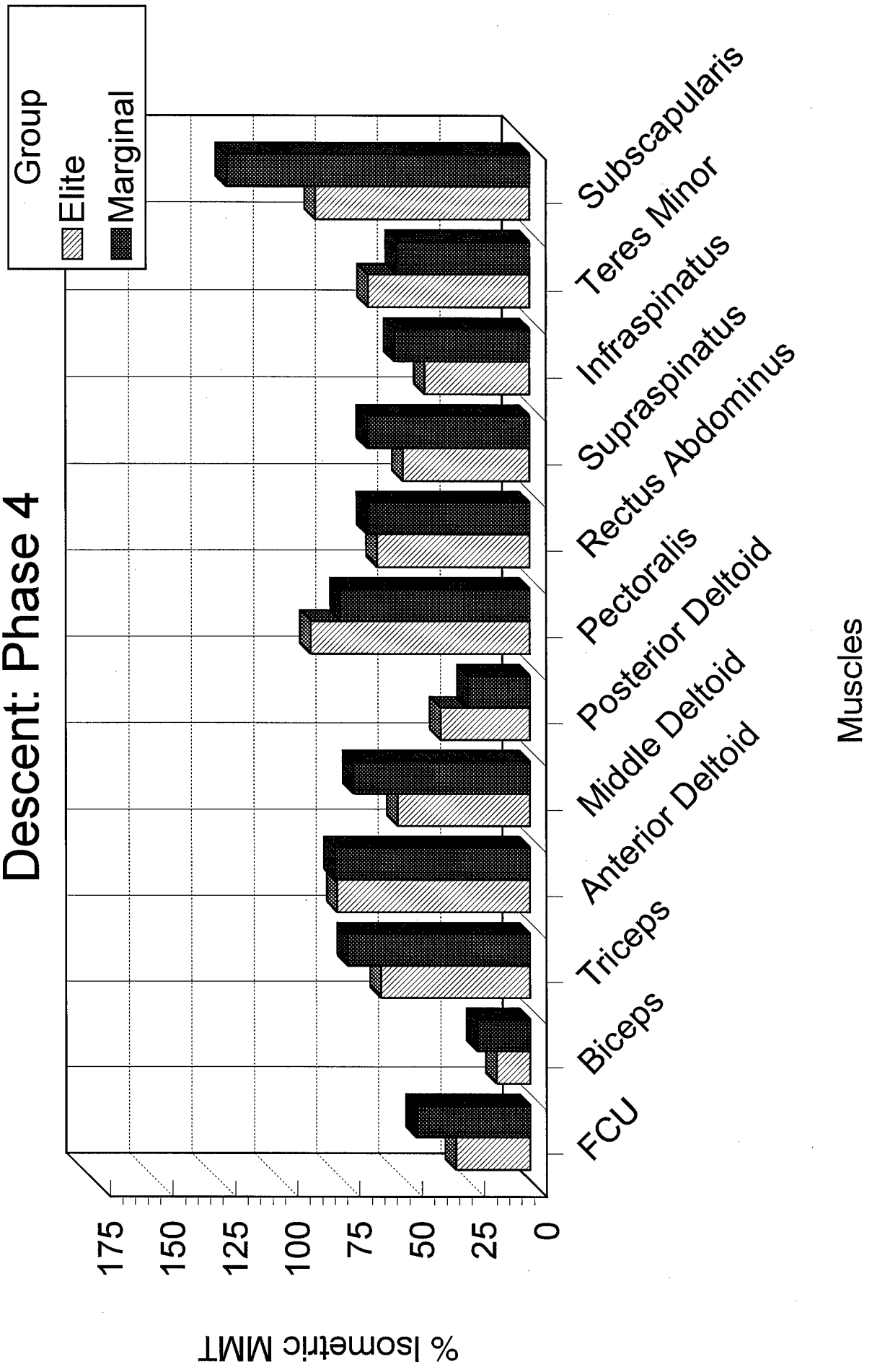


Descent: Phase 2

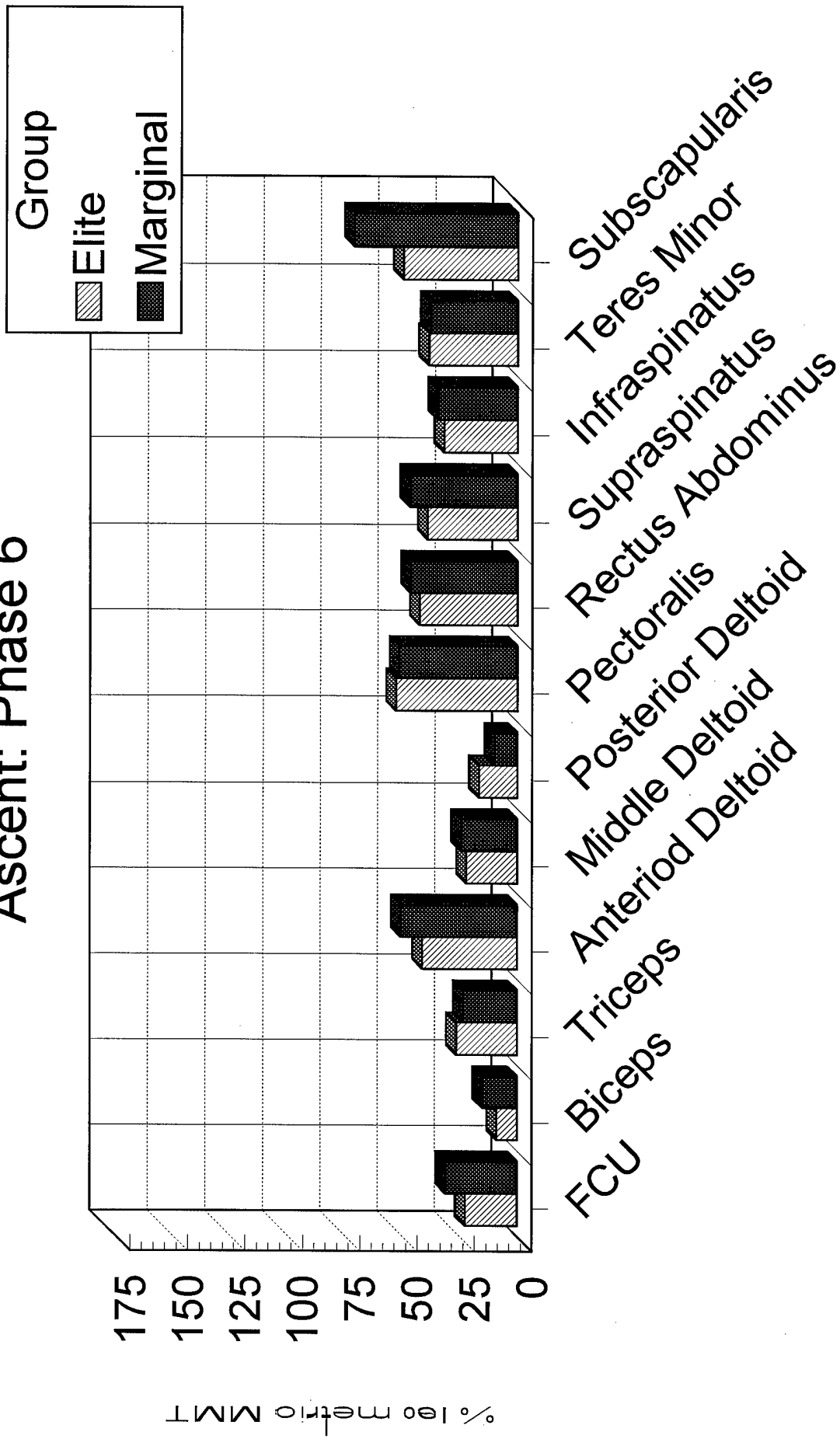




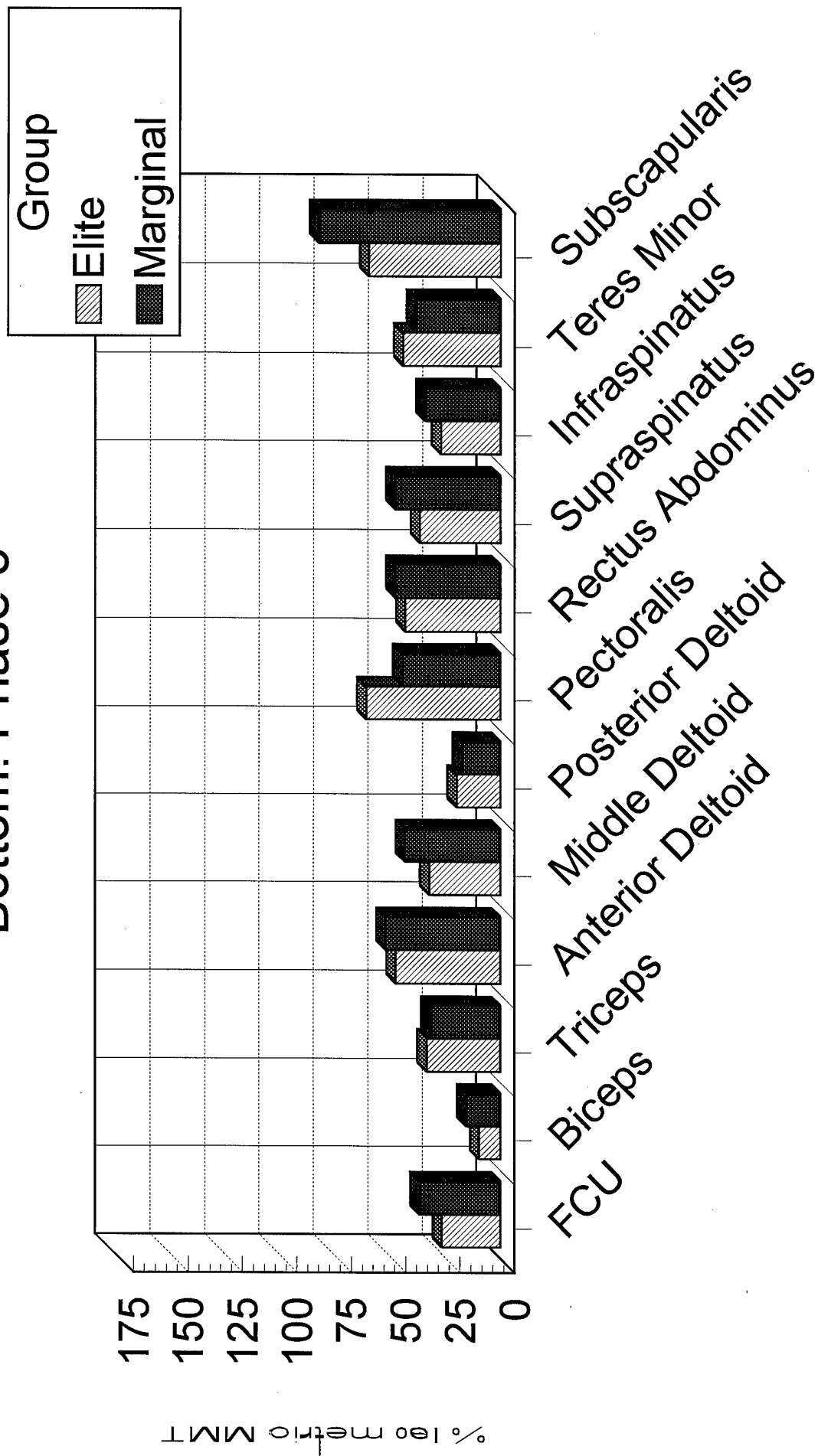
Descent: Phase 4



Ascent: Phase 6

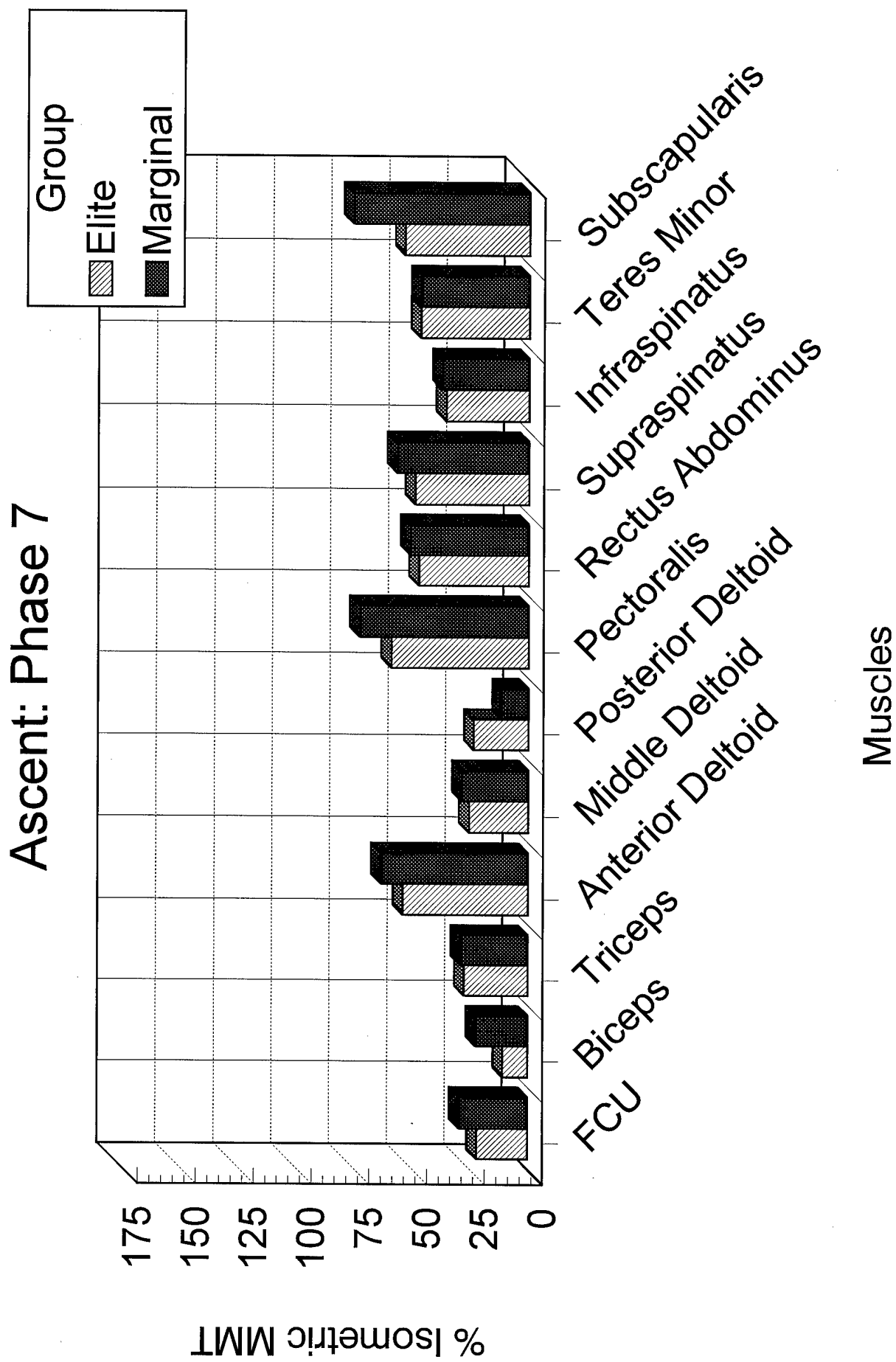


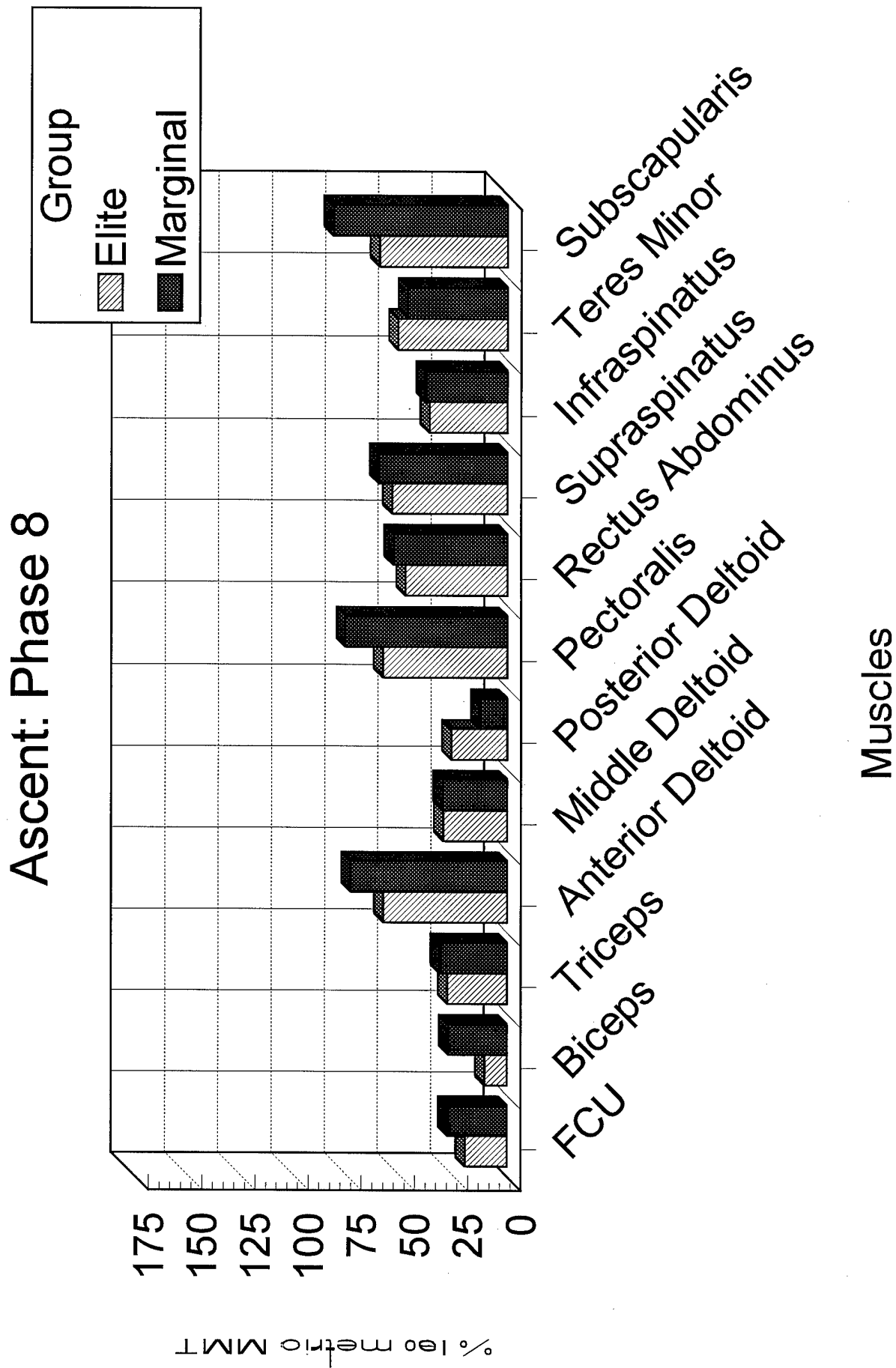
Bottom: Phase 5

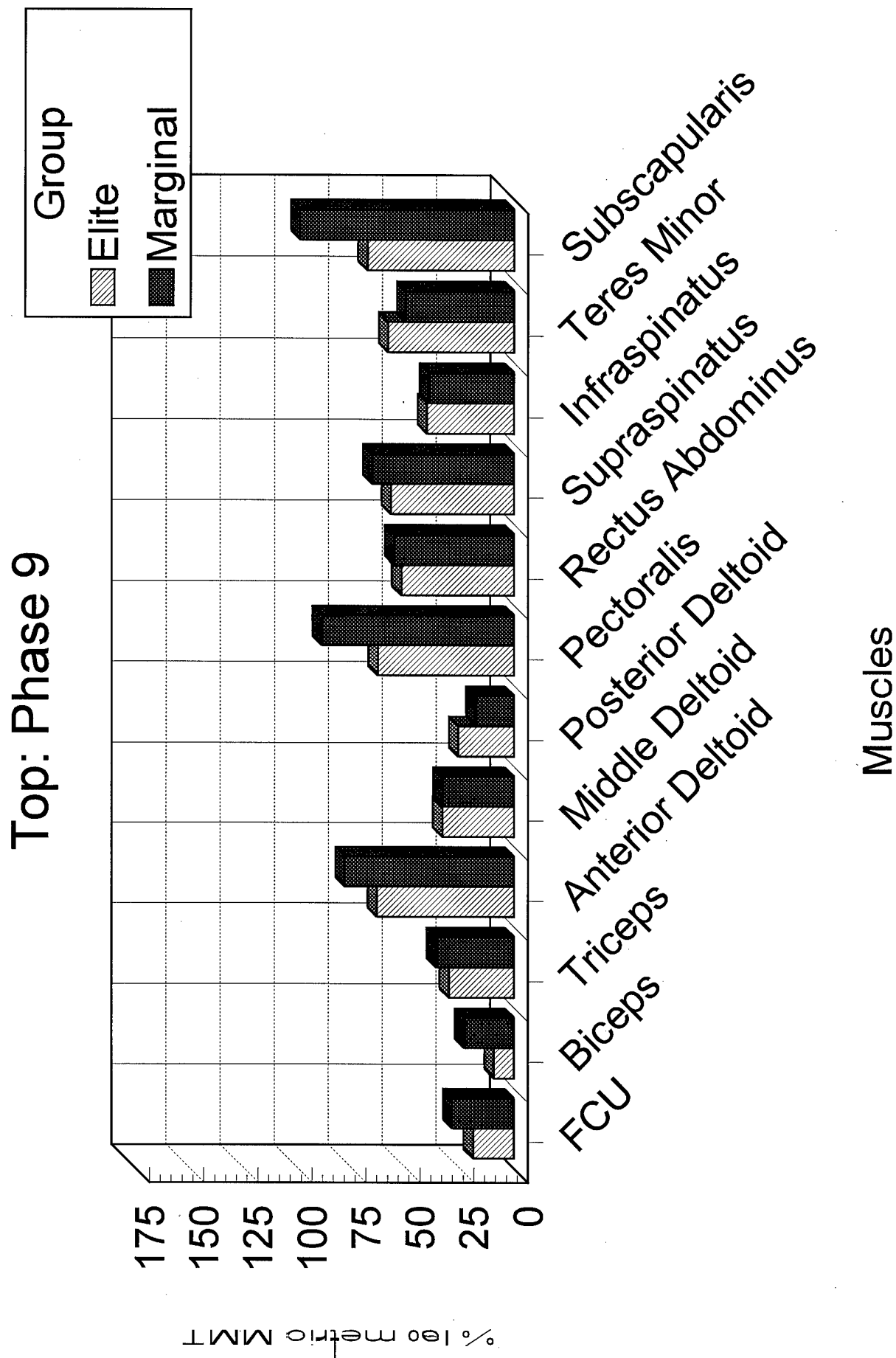


Muscles

Figure 19







Bibliography

No abstracts or articles have been published from this research at this time. An abstract has been submitted for presentation of this work at the American Academy of Physical Medicine and Rehabilitation Annual Meeting in Chicago, IL, November 1996. Acceptance is pending.

Final preparation is also underway for submission of an article based on this research to the Archives of Physical Medicine and Rehabilitation. A copy of the submission will be forwarded to you prior to its submission for review.

Paid Personnel

Beatrice J. Park, RN, CRRN was hired as research coordinator for this project.

No other individuals received remuneration for this project.